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LAND DRAINAGE

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FOREWORD

This book deals with the subject of drainage primarily from the agricultural standpoint, and the subject has been developed largely as a matter of applied soil-physics. Drainage is considered herein as a means of reclaiming additional areas and of making wet lands more productive. Reclamation of arid and wet lands affords the chief means of increasing our food producing areas and drawing a greater proportion of our population into the rural districts.

The present volume is intended, first, as a text book for students of general agriculture or agricultural engineering; second, as a reference book for practical farmers; and third, as an aid to owners of wet, overflowed, marsh, swamp or alkaline land who desire to improve their holdings.

The information presented herein has been gathered by the authors, as farmers, students and instructors, in the Corn Belt States and later in the West, where preliminary feasibility surveys and selection of lands for irrigation projects and drainage projects have been an important feature of our work. Review questions, general references and laboratory exercises have been included to help make up the kind of a book that has seemed to the writers to be needed.

W. L. POWERS

CORVALLIS, OREGON
December 10, 1921

Land Drainage

PART I. — FIELD DRAINAGE

CHAPTER I

DEVELOPMENT, IMPORTANCE AND FUTURE OF DRAINAGE

THE removal of excess water from wet lands by drainage acquires a more vital importance as a greater proportion of the naturally arable land is brought under cultivation. Wet spots hinder farm operations and transportation in occupied farming areas; and the drainage of such spots grows more imperative as values become higher and agriculture more intensive. The intermittent nature of rainfall, and the variations in soil and topography necessitate artificial control of excess water. The reclaimable marsh lands, in the United States alone, embrace approximately 75,000,000 acres, or an area about twice that of the state of Iowa, while the wet farm land includes several times this area. Opened to settlement and cultivation, this land would increase, to an almost incredible extent, the value of our possible annual crops. The peoples of the earth must be fed; and the drainage of wet but fertile and accessible lands is of fundamental importance in providing food and homes for the increasing population. The public marsh lands in the Central States were largely disposed of a generation ago at $0.01 to $1 an acre. These lands, where reclaimed, have acquired a value of $100 to $200 an acre. It is evident from these figures that a comprehensive public policy of reclamation should be perfected.

Drainage in Europe. — Stone, brush, and open drains were described in the writings of Columella, who lived during the

first century of the Christian era. The earliest known example of tile-drainage was discovered in 1620, in the "magic garden" of a monastery in France, where the soil was very fertile even in times of drought and the quality of the fruit was remarkable. Investigation revealed that tile 10 inches long and 4 inches in diameter had been laid in the soil, in such a manner as to form a drain at a depth of 4 feet. Each pipe was funnel-shaped and made to fit into the next one. We do not know how early they were placed there.

A book on drainage was published in 1650, by Captain Walter Bligh, who advocated drainage trenches. In 1764, Joseph

Fig. 1. Land practically worthless through lack of drainage.

Elkington of Warwickshire, England, advocated tapping underground springs along hillsides, and conveying their water away before it came to the surface.

Drain-tile was first used in England in 1810, on the estate of Sir James Graham, in Northumberland. The tiles were made in two pieces, the top being in the shape of an inverted U, and the sole a flat plate upon which the tile was placed. This type of tile was used for thirty years.

The Deanston system of clay pipes was introduced in 1832

by Mr. Smith of Deanston, Scotland. The following year he published a pamphlet entitled " Smith's Remarks on Thorough Drainage." The features of the plan were as follows: 1. Frequent drains. 2. Shallow depth, (about 30 inches). 3. Parallel drains at equal distances throughout the field. 4. Minor drains running down steeper places and main drains along cliff hollows, with tributary drains for lesser hollows.

A tile-machine was made in England in 1843, and rapid development followed. Government aid has been given, and large projects have been established in Europe during the last century.

Notable European Projects. — Elliott describes two immense drainage projects in the Old World. One of these, the English Fens, embraced 700,000 acres of tidal and overflowed lands

FIG. 2. Same land shown in Fig. 1 after drainage and growing a crop.

which were reclaimed by levees, ditches, and pumping plants. The work covered a period of two centuries and added an area, " dotted by thrifty towns and traversed by railroads of national importance " the gross product of which is worth not less than $30,000,000 per year.

Haarlem Lake, Holland, is another striking example of successful drainage. The lake formerly covered an area of 43,700 acres. Between 1840 and 1852, the Dutch Government reclaimed this tract by means of immense canals and pumps.

It was then divided by means of interior ditches, into fields of 50 acres each. The net land area, 42,300 acres, was drained at a cost of $5,516,000 or $128 an acre, and sold to settlers at $80 an acre. Such a policy is, of course, only possible in a government enterprise, the state being one concern that can afford to improve land at less than cost plus interest. Sixteen thousand people now occupy the reclaimed land, which produces much of the food raised in northern Holland.

The Zuyder Zee drainage project in Holland, one of the world's greatest engineering projects, has recently been authorized by the Dutch Government. It involves the construction of 30 miles of dike to hold out the North Sea, as well as three large pumping stations. Most of the land which is to be reclaimed lies 13 feet below sea-level. This will be unwatered in from fourteen to thirty-five years. The project embraces 827 square miles and its cost will be in excess of $125,000,000. The work will be done and paid for by the state, which expects to repay itself in a few years and thereafter possess a valuable province capable of supporting a population of 300,000 people.

Drainage in the United States. — Mr. John Johnston of Geneva, New York, introduced tile-drainage into that state in 1835. A drain-tile machine was imported in 1848; and by 1851 Mr. Johnston had laid 16 miles of tile, and so improved a wet clay farm that it was purchased for nursery purposes.

Central Park, New York City, was drained in 1858. It contained 856 acres, and was the largest thorough drainage project undertaken, up to that time, in the United States. In 1867, Colonel Waring, the engineer in charge of this work, published a book entitled "Drainage for Profit and for Health."

Previous to this date, diking and ditches had been used in the South, in connection with rice culture, and mosquito and flood control. Meanwhile, in the Corn Belt states, the tillable land was increasing in value, and farmers were learning that the wet lands yielded to drainage and became very valuable corn land.

Among the outstanding features in the development of drainage in the United States may be mentioned (1) the enactment

of district drainage laws, (2) the improvements made during the eighties in machinery for dredging and pumping, (3) improvements in concrete construction, (4) the establishment of numerous tile-factories and the use of larger tile, and (5) the introduction of dynamite as a means of clearing a right of way through wooded land.

During the last decade, important drainage work has been accomplished in the irrigated sections of the West. Interest in drainage now extends to the Pacific Coast, where tidal overflowed and wet lands are being reclaimed and hundreds of miles of tile are in use.

Extent and Importance of Drainage. — Mr. C. G. Elliott, the former Chief of Drainage Investigations, in a report made to Congress in 1908 on unreclaimed swamp and overflowed lands and wet lands of the United States, estimated the extent of these lands as follows:

52,665,020 acres of permanent swamp land, mostly reclaimable
6,826,019 acres of wet grass land
14,747,805 acres of periodically overflowed land
4, 766,179 acres of periodically swampy land
150,000,000 acres of occupied farm land needing drainage,

or a total of 229,005,023 acres, or 357,820 square miles — an area $4\frac{1}{2}$ times that of Iowa — needing drainage, and an area $1\frac{1}{4}$ times the size of Iowa reclaimable by drainage.

Drainage of these lands Mr. Elliott regards as a matter of importance to public health and an inestimable service to agriculture. Every state in the Union contains lands in need of drainage, the areas varying from 8000 acres in Rhode Island to 20,000,000 acres in Florida, where enormous projects have been outlined.

The estimated increase in land values and in annual income from draining the swamps and the overflowed lands in the United States is placed at $1,593,633,155 and $273,079,295 respectively.

It has been estimated that about 18 per cent of our irrigated

lands are in need of drainage. Extensive arid and alkaline areas, as well as water-logged wild meadows, are reclaimable through drainage and water-control. Drainage of tidal and overflowed lands, and control of erosion and seepage may be accomplished through the use of levees, tile systems, and pumps.

According to our present knowledge, some 75,000,000 or more acres in the United States will ultimately be reclaimed, while a much greater area can be benefited by drainage. There is a growing interest in drainage throughout the country.

Advantages of Drainage Reclamation. — We readily spend $40, $60, and $80 an acre to irrigate lands that produce as much by dry-farming as our wet lands yield in their present condition.

Lands that require drainage are generally of good depth, well supplied with plant food, and located where there is a long growing season. As a rule, they are favorably located with regard to markets and transportation and are free from hard-pan or rock. It is believed that much of this wet soil, if drained, would pay a good rate of interest on total investment. Drainage is a permanent improvement and one of the best that can be made in a wet region.

Federal and State Aid. — In 1846, Great Britain created a loan of $10,000,000 for England and $5,000,000 for Ireland, to be advanced to farmers for drainage purposes. Repayment is made in annual installments. France has also loaned money and furnished engineering assistance to farmers, while Belgium and Germany have built factories to make tile at low cost.

England permits private improvement companies to construct drains and make loans, which are secured by rentals. France furnishes engineers, free of expense, to farmers. The province of Ontario, Canada, loans as much as $1000 to a farmer and allows twenty years for repayment, at the rate of $7.36 annually for each $100 loaned. Vermont has a similar arrangement.

The United States Department of Agriculture, Division of Drainage, investigates, conducts experiments, makes surveys,

and publishes bulletins. The various states conduct experiments, publish bulletins, and give assistance and instruction to landowners through agricultural colleges, experiment stations, and extension service. The experiment stations have conducted experiments with tiling in wet soils and have developed and applied successful methods of draining and improving these lands. Surveys have been made to determine the feasibility of possible projects. The agricultural colleges, through their extension service, conduct field demonstrations and design field tile systems, demonstrating the use of ditching machines and assisting in the organization of drainage districts. Public sentiment is becoming more favorable to a comprehensive plan for reclamation. Numerous reclamation measures have been introduced in Congress and a comprehensive national policy of reclamation may be expected to develop before long.

Drainage Organizations and Institutions. — State drainage district laws have developed and made possible community and district drainage enterprises extending over millions of acres in some states.

The National Drainage Congress was organized in November 1911, in Chicago. It is composed of engineers, landowners, capitalists, and others interested in drainage. Several states, including New York, Louisiana, Wisconsin, Iowa, and Oregon, have drainage organizations which meet annually; and the reports of their proceedings are valuable. There are also some important flood-control commissions. These organizations are affiliated, and strive to aid drainage development by providing publicity and proposing needed legislation.

QUESTIONS

1. What conditions give rise to poor drainage?
2. Why is drainage of public importance?
3. What records are there of early drainage in Europe?
4. Describe some large European projects.
5. What improvements have aided drainage development?
6. Where and when was tile first used in America?
7. State the advantages of drainage.
8. Outline past and present drainage measures.

9. What aid is given in land drainage by the experiment stations and by extension service?

10. What organizations and institutions have assisted drainage development?

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CHAPTER II

BENEFITS OF DRAINAGE

THE benefits of drainage consist in improved soil, plant and water relations. Drains are installed to increase crop production and to enhance the value of wet land. The following are the main reasons why drainage increases the productive capacity of the soil.

1. *Removes excess water.* — The primary object of drainage is to lower the water-table, or remove the excess free water in the soil, so that the larger pore spaces may contain some air. The drainage-water can frequently be used for stock water or irrigation.

2. *Increases the capillary supply of moisture.* — A drained soil is in a better state of tilth than one in need of drainage, and therefore contains more pore space and more room for air and for usable soil-moisture, or capillary moisture. When the water-table has been lowered, there exists a deeper zone in which capillary moisture can be stored and used by crops. For this reason, well-drained land contains more moisture in time of drought.

3. *Improves the soil-structure.* — Drainage is of great assistance in improving the soil-structure. It permits the soil to be worked when it contains the proper amount of moisture to make it crumble into a mellow state on being plowed. Drainage allows plants to root deeply, and form fibrous vegetable matter in the subsoil. This causes a mellow structure and facilitates cultivation.

4. *Increases the root-pasturage.* — If a water-table which is within 1·foot of the surface is removed by drainage to a point 3 feet below the surface, the zone for feeding roots is thereby trebled. This enables plants to develop deep roots and acquire more resistance to drought. Drainage frequently makes it possible to establish deep-rooting crops.

5. *Affords better air circulation.* — Removing the free water from the large empty spaces in the soil makes room for more air. If the water is kept moving downward and out through the soil, additional air is brought into the soil by suction.

Fig. 3. Drained and undrained White Land. Land to the left due to drainage has produced good crops, to the right the land is undrained.

Moreover, the presence of drains brings air into contact with the soil, and is an aid in aeration and the liberation of plant food, making it possible to use fertilizers to better advantage.

6. *Makes soil warmer.* — A wet soil is a cold soil, because the temperature is lowered by excessive evaporation at the surface. Drained soil is warmer and permits better and earlier germination. Experiments at the Oregon stations have shown soil to be from 3 to 8 degrees warmer when drained.

7. *Lengthens the growing season and firms the soil.* — Drainage makes the soil firm earlier, so that the whole field can be worked at the proper time. It makes possible the raising of legumes or long-season crops and cultivated crops where formerly only grasses, swamp growth or weeds existed. Ontario Agricultural College found that a large number of fields, on which reports were made, were planted from one to six weeks earlier after being drained.

8. *Assists decay and nitrification.* — Those soil bacteria

which cause the decay of vegetable matter and aid in nitrification require the presence of oxygen and nitrogen in the soil. As these two elements must be obtained from the air, good aeration is necessary to the work of nitrification. In water-logged soils, denitrifying bacteria, instead of nitrifying bacteria, are at work.

9. *Prevents erosion.* — Drainage permits the excess water to pass through the soil instead of over it, so that plant-food is carried into the subsoil and held there. In poorly drained areas, runoff removes the most valuable soil from the surface.

10. *Diminishes the effect of drought.* — Crops on drained soil are better able to withstand the drought, because the soil is in better structure or tilth. It contains more vegetable matter from deep roots; it has a larger reservoir for usable soil-moisture; and the plant roots are consequently deeper. Well-drained plots on the Oregon Experiment Station, at the close of the dry season in September, 1916, were found to contain an average of 2 per cent more moisture than adjoining plots with similar crops and poorer drainage.

11. *Prevents heaving and freezing out* of clover and other plants of this character. In wet soils freezing and thawing causes the crowns of the plants to be lifted, and the roots exposed to the cold weather.

12. *Prevents the rise of alkali.* — Where there is natural underdrainage, or artificial underdrainage at a suitable depth, excess soluble salts are kept moving down and out through the drains, so that alkali does not accumulate. Soil acidity may be removed or its increase largely prevented by drainage.

In addition, drainage improves sanitary conditions, promotes healthfulness and is an aid to transportation and to the general development of a country. Timely drainage pays big interest on the money invested, by increasing the yield and the value of the product.

Successful Drainage Practise. — A circular letter was mailed in 1914 to a list of farmers in western Oregon who had tiled their land. The purpose of the letter was to learn something of the extent and success of tile-drainage. About fifty replies

were received, over forty of them giving answers to the questions asked.

The replies came from farmers who had had from three to thirty-five years' experience with tiling in the "white land" and other common soil types of the Willamette valley. The reports cover experience with approximately 100 miles of tiling, draining several thousand acres of low land and costing, for the total area affected by the drains, about $10 an acre.

The average fall reported for drains in operation was about 1 foot for each 100 feet. Eighty per cent of the tiling was laid by water grade, while the rest was laid with the aid of a surveyor's level.

The average wage for digging trench and laying tiles for 4-inch laterals, 3 feet deep, was reported as $0.30 a rod. Most of the ditches were refilled by the use of a plow with a long evener. Under fair soil and weather conditions, the amount dug and laid each day averaged about 100 feet for each man. Under good conditions as much as 1 rod an hour was installed.

Question 23, in the circular letter, read, "Has your drain system handled the excess water as well as expected?" Thirty-nine farmers answered this question. Thirty-six of these replied "Yes"; one replied "Better"; one replied "Yes, except in small lateral"; and one stated that tiling "did not handle flood-water as expected."

Question 24 read, "Has drainage improved your soil?" Twenty-nine replied "Yes." The other replies to this question were as follows: "Wonderfully," "Very much," "Indeed it has," "Greatly," "As far as completed," "Too soon to tell."

Question 26 read, "Do you consider that drainage pays under your conditions?" Thirty-seven answered "Yes." The other replies received were "Decidedly," "Certainly," and "It pays big." There was no negative reply.

Question 25 read, "Can you cite any definite results?" Replies to this question were generally favorable, and some should prove of interest. One replied "One hundred per cent better"; another, "Soil can be worked earlier in the spring." Other replies were as follows:

"We lost 150 prune trees out of 500 set out before draining, and only 300 out of 7400 set out after draining."

"Before draining, water stood on the field all winter; but now it drains after only two days."

"The land is dry enough to farm and produce good crops, where before draining it was waste."

"Yes, one-half of the field could be used only for spring crop, and then dried out hard as a bone. Now, with drainage, it is better than the other fields."

"Yes, land that formerly did not pay taxes now produces good crops. I consider that tiling has doubled the output of the farm, and the system is not yet completed."

"We get fair crops now, and obtained nothing before draining."

"Land can be worked more conveniently and earlier."

"Yes, could not raise winter wheat on the land previous to tiling; since tiling winter wheat does well."

"Yes, we can plow wet spots a month earlier on some soils."

"I put in about 3000 feet each winter. One-year-old ditches are drying the ground about 10 feet wide, two-year-old ditches 20 feet wide and three-year-old ditches 40 feet. I had black soil that was hardly paying taxes before tiling. Since tiling, I have fine corn, clover and kale, and not any water. It would be best to come and see the real benefit. There is but little wet land in this section that it would not pay to tile."

"Our drainage system is fifteen to thirty-five years old and handles the excess water so that ground can be plowed after we have had two days of clear weather following any hard storm. The drainage system has improved soil fully one hundred per cent."

"After the soil is thoroughly drained, it becomes very porous and will hold the moisture in dry weather fully one hundred per cent better. The soil becomes warm and the rootlets of crops can penetrate the soil a great deal deeper."

"I am more than satisfied with my drains. The main drawback to drainage is lack of funds. I am putting in about 3000 feet more this winter. Last summer I raised corn 8 feet

high on what was the very wettest part of my farm before draining; and my oats were doubled in yield. Three neighbors are putting in a little tiling as a result of my making a start last winter."

"Yes, land that formerly did not pay taxes now produces good crops. I consider that tiling has doubled the output of my land and the system is not yet complete. I certainly do consider that it pays."

"Yes, where once was a swamp I now raise 50 to 90 bushels of oats to the acre."

"Indeed, I have drained my land with success; I would rather have 160 acres of drained land than 320 undrained, if I had to live on it and farm it."

Profits from Drainage. — Timely drainage usually pays in increased crops and increased land value. Those who have drained say that it pays. The writer has examined most of the tile systems in use in Oregon and many systems in the Central States; and, while a few drains in use are too small or too deep, or have been poorly constructed, he has failed to find a tile system properly installed which has not been successful.

Tile-drains usually improve for years. If properly installed, they should increase the value of the land by an amount equal to their cost. The profits from drainage are so large that drains frequently pay for themselves within a few years. It costs money to hold wet land and most of our wet lands will pay a better rate of interest on the total investment if drained. Drainage is a permanent improvement; it is the fundamental step in the improvement of our wet lands; it makes rotation with soil-building crops possible and constructive soil treatment effective.

QUESTIONS

1. Name twelve agricultural benefits from drainage.
2. What non-agricultural benefits result from drainage?
3. Explain how tiles remove excess water.
4. Give reasons why drainage increases the space available for usable soil moisture.

5. How does drainage increase root-pasturage and resistance to drought?

6. Why is air necessary in soil, and how does movement of free water affect aeration?

7. Why is unsaturated soil firmer?

8. What conditions are necessary for decay and nitrification?

9. What is "heaving," and how is it controlled by drainage?

10. How does drainage aid control of soluble soil acid or alkali?

11. Give examples of successful farm drainage.

12. In what ways may profits be realized from drainage?

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CHAPTER III

THE RELATION OF SOILS TO DRAINAGE

Surface Geology and Drainage Conditions. — Drainage is concerned largely with two materials, soil and water. All soil must have drainage to remove excess water; but in many cases the land has natural drainage, through channels cut out during the formation of the earth's crust. Where the country is geologically old, running water has usually cut out natural drainage channels and completed valleys, so that there is comparatively good natural drainage and artificial drainage is not needed except to control erosion.

The geological conditions giving rise to poor drainage are as follows:

1. Bodies of rock formed by faulting of the earth's crust, or by lava flows, often temporarily obstruct the natural drainage system of a country. A water course is frequently divided into three parts, the upper, middle and lower valleys, in all of which the stream is more or less meandering. Between these divisions the river cuts through rock and is confined to a narrow canyon, where it has little or no effect on the drainage of the region.

2. Shale ridges are common in the hill lands of the Pacific coast region and in the bench lands in the interior valleys. Former inland seas or lakes developed shore lines which remain in the form of shale ridges in the subsoil.

3. Heavy clay occurs in the subsoil as a uniform layer, or as hogbacks or dikes. In places, the hard clay subsoil may be in the shape of pockets. These dikes and pockets interfere with the subsoil drainage, and cause water-logging of the subsoil and seeped spots on the surface. Frequently the topography of the surface is very uneven and is hard enough to interfere with drainage, some rather firm material being present in the subsoil.

4. Beaver-dams or accumulations of fallen logs and other vegetation may interrupt the outlet of a flat area and give rise to a growth of marshy material. Frequently the vegetable matter accumulates under water faster than it decays, giving rise to an organic soil. Silt deposits may help to complete such an obstruction.

5. Moraines interrupt the surface drainage of the glaciated country. Odell Lake and other lakes on the east side of the Cascades are glacial lakes formed in this way. Old Lake Kankakee, or the Kankakee Marsh, in northeastern Illinois and northwestern Indiana, is a great marshy area of this kind that has been largely reclaimed by drainage.

6. Large areas of low-lying land or flat land with retentive subsoil will require artificial drainage, if the climate is wet.

Effect of Soil-Texture on Drainage. — Normal soil is inorganic material mainly derived from the weathering of rock on the earth's surface. It is classified, according to size of the component particles, into sands, silts, and clay. Sands

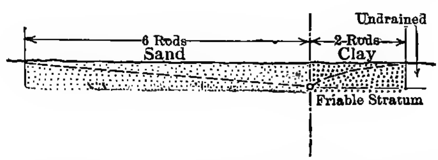

Fig. 4. A comparison of the effect of drains in sand and in clay.

and sandy loams, or those soils which are free-working, are usually naturally drained or when artificial drainage is necessary, can be readily drained by means of a few deep drains placed rather far apart. The fine-grained soils, like the clays, have a great surface area, and their pore space is very finely divided. Owing to the friction developed by the small particles which compose them, these soils take up water very slowly and hold it stubbornly. Clays are also inclined to puddle.

Heavy Clay. — Adobe, locally called "sticky," is a heavy clay soil containing 40 per cent to 60 per cent clay. It occurs in many valleys in the Southwest and in the Pacific Coast

region, as well as in other sections. It is doubtful whether thorough underdrainage of these sections is at present justified. Surface drainage can be provided within the "sticky" areas, and the water can be cut off before it reaches them. Clay subsoil under the "white lands" of the Willamette valley is very putty-like and renders this soil difficult to drain. Similar areas of retentive soil occur in Missouri. Drainage of tight clay in the South Central States is also extremely difficult. In dealing with areas that have a heavy clay subsoil, it is best to locate the drain over, under or around these areas as much as possible, picking up the water before it reaches the retentive soil, or, if they are saucer-shaped areas, providing catch-basins in the lowest portions. These catch-basins will permit the water to enter the drains more readily.

Occasionally we find a sand-clay, or a soil that contains a very appreciable amount of grit but is cemented together with clay so that it is very putty-like and difficult to drain. Collecting wells may be useful in such soils to bring water to the tile. Drainage is the first step in the improvement of these retentive soils; it is necessary before lime of other fertilizers can become effective. We should drain first and then use lime, manure, and deep tillage.

Organic Soils. — Deep peat soil is easily drained where outlets are available, and makes good land, although it may need chemical treatment. If shallow, a sand or shale substratum facilitates drainage more than silt or clay.

Muck contains decayed vegetable matter and silts, and requires more thorough drainage.

Effect of Soil-Structure on Drainage. — Soil particles usually occur in clusters. Where the soil is in good tilth there are pore spaces between the individual soil particles in a cluster, and larger pore spaces between the clusters, as in popcorn when it is mixed with syrup. In a puddled condition, the soil particles are dove-tailed together and the finer particles filtered in between the coarser ones, so that there is a minimum of pore space and a maximum density, the arrangement being similar to concrete. In a water-logged soil, the cementing

materials have been dissolved, and, as the soil is saturated, the films of moisture, such as hold moist beach sand together, are eliminated, and the soil yields like dry sand or sand under water. Under these circumstances there is nothing to support the soil-structure and it collapses, allowing the particles to run together. Bad structure makes soil slow to drain and, conversely, an improvement in drainage works a corresponding improvement in soil-structure and gives stability to the soil.

Importance of Subsoil Examination in Drainage. — Underdrains must operate in the subsoil; and, from a drainage stand-

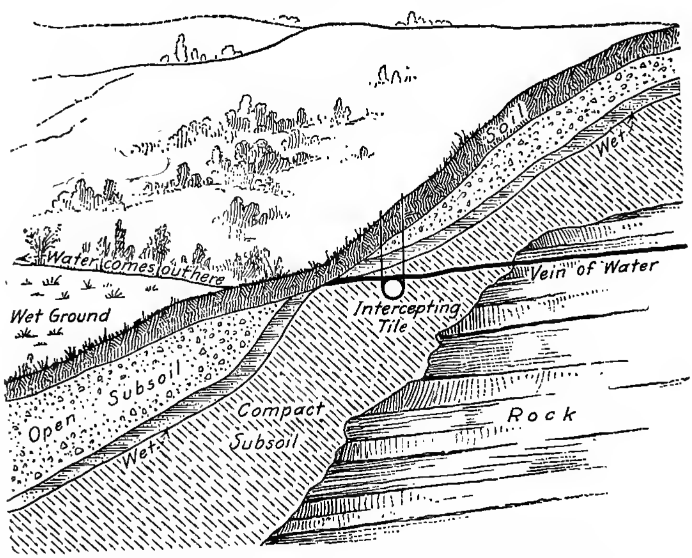

Fig. 5. Sketch showing the effect of impervious soil stratum upon drainage and the use of intercepting tile.

point, the subsoil is more important than the surface. In most of our wet lands the subsoil lacks aeration, is lighter in color, finer in texture, and contains less organic matter than the surface. Excessive moisture has prevented crop roots from penetrating into the subsoil as they would if the soil were drained. Heavy substrata must be located by the use of a

soil-auger free and the tiles must be located in the free-working soil, avoiding these heavy strata as much as possible. Occasionally, it will be necessary to cut through a hard substratum so as to provide an outlet and dispose of the excess water by means of gravity.

The subsoil of an arid district is different from that of a humid soil in that it is less uniform, and is more apt to contain alkali hard-pan or gravelly strata. The wet soil of a humid climate usually develops a system of tiny veins through which water travels. No such system is developed by the arid soil.

Effects of Hard-Pan upon Drainage. — Hard-pan in the subsoil is caused by the deposition of substances from solution. It occurs where percolation ceases, and interferes with the movement of free water, causing at least a local water-logging of the overlying soil. In some cases the hard-pan may be broken up with dynamite, and vertical drainage may be established. In other cases, hogbacks in the hard-pan can be cut through, so as to afford a drain that will remove the water. Common cementing materials found in hard-pan soils are colloidal clay, lime, iron, soluble alkalies, and silicates. Lime acts as a powerful cement in combination with humus. Plowing to uniform depth or pasturing with sheep in wet weather may puddle the soil at the bottom of the furrow-slice and cause a "plow-sole," which interferes with drainage. Artificial drainage will frequently renew percolation, redissolve the cementing material and correct the conditions which have hindered natural drainage.

Slacking of subsoils, when they are thrown out of the drainage ditch or exposed, is due to shrinkage of the clay contained, oxidation of the minerals, and probably also to a rearrangement of the soil-moisture films.

Lands Needing Drainage. — Following the classification of wet lands by Kind, our wet soils may be grouped as follows:

(1). Nearly flat lands where water from surrounding uplands collects. Ponds are in this class.

(2). Areas adjacent to higher lands, permitting seepage. Steep hill lands in humid sections, and the

seeped alkali lands in the irrigated valleys of the arid region are in this class.

(3). Lands inundated regularly by overflow from rivers or tides. The wet lands along the coast, lower flood-plains of large streams, and the lands in the marshes surrounding lakes may be included in this class.

(4). Flat lands in wide areas underlain by a retentive subsoil. "White lands" are of this class.

(5). Irrigated cranberry marshes, rice lands, etc., where an excess of water is applied and must be removed again.

Preliminary Studies. — The first step in laying out a drain system is to make an examination of the soil and subsoil conditions by the systematic use of a soil-auger. This will reveal the presence of gravelly strata through which seepage travels, or of hard strata over which seepage-water is moving. Putty-like layers will also be located in this way, and the drains can then be located over, under or around these layers, so as to collect the water in spite of the retentive areas in the subsoil, and convey it away as directly as possible.

QUESTIONS

1. What geological conditions cause poor drainage?
2. Explain the relation of soil-texture to drainage.
3. Describe the characteristics and drainage qualities of adobe, sand, clay, peat, and muck.
4. Distinguish between puddled structure and good structure.
5. What is the relation between texture and structure in soils?
6. What is the relation between soil-structure and drainage?
7. What substances cause hard-pan?
8. How does hard-pan affect drainage?
9. What is a "plow-sole," and how does it affect drainage?
10. How should subsoil examinations be made and what points should be noted in making them?
11. Compare the soils of humid and arid regions with regard to the character of the subsoils.
12. What different types of localities need artificial drainage?

13. How can the drainage requirements of a field be determined?
14. What causes slacking of subsoil when exposed?
15. How should tile be located with reference to sticky soil bodies?

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CHAPTER IV

RELATION OF SOIL-WATER TO DRAINAGE

Forms of Soil-Water

In drainage we deal with gravitational water, or free water, a form of water which may be seen to move downward through the soil by means of gravity. It is the water that fills the larger pore spaces and causes soil to be saturated or water-logged. Most field crops will not do well with their roots in saturated soil. Crops can tolerate more or less free water, if it is kept moving, or is " live water," and contains some air. Water may become usable soil-moisture after it has been drawn up by capillarity into the soil above the plane of saturation or water-table. It is then known as capillary water. The water-table is also called " water-plane " and " sheet water." The amount of moisture in soil decreases with distance above the plane of saturation. Forms of soil-moisture and important moisture points are indicated in Fig. 6.

The rate of flow of soil-water depends mainly on the available head or gradient, relative porosity of soil, and temperature.

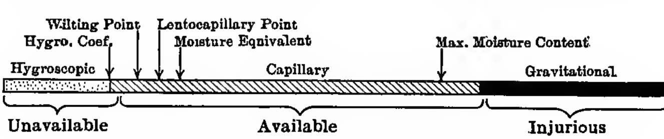

Fig. 6. Diagram showing forms of soil, moisture and important moisture points.

In Table I, summarized from U. S. Geological Survey data,[1] the velocity of flow is based on a fall or grade of 100 feet to the mile, a porosity of 32 per cent and a temperature of 50° F.

[1] Fortier S. H. Use of water in irrigation.

TABLE I. — RATE OF FLOW OF SEEPAGE-WATER AS AFFECTED BY SOIL-TEXTURE

Kind of Soil	Diameter of Soil Grains, mm.	Velocity	
		In Feet a Day	In Miles a Year
Silt	0.01	0.0038	0.00026
Very fine sand	0.05	0.0923	0.00638
Fine sand	0.10	0.3690	0.02551
Medium sand	0.25	2.3050	0.15940
Coarse sand	0.50	9.2240	0.63770
Fine gravel	1.00	36.9000	2.55100

Toleration of Water by Crop Roots. — If the water-table is near the surface the plants will not send roots into it, but will be shallow-rooted. If the water-table rises and remains close

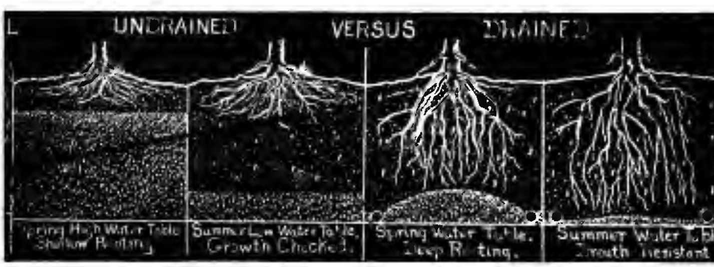

Fig. 7. Effect of drainage on the roots and drought.

to the surface, the roots will be rotted off. Alfalfa usually dies out in three or four years if the water is less than 4 feet from the surface. Grain, red clover, onions, and potatoes need about 3 feet of unsaturated soil to mature well, and Alsike clover, 18 to 30 inches; rye-grass, redtop, and timothy will grow with 12 inches of soil above sheet water, but are apt to give way to water-grasses and less desirable growth.

Water-Table Observation Wells. — A series of borings or small wells is often installed in a regular line or at selected points, to aid in the study of underground water conditions.

Temporary borings made with a soil-auger can be used in some soils; but the auger will puddle the soil somewhat and the exact elevation of the ground-water cannot be determined for several hours. However, the character of the soil and the source of the water may be indicated by the boring; and notes should be taken of the core as the well is made. The elevation of the surface at each well can then be determined with a level and, at regular intervals thereafter, readings can be taken of the water-stage in each well. A graduated hollow tube may be used to determine accurately the depth of soil above water. Placing the mouth to the tube and breathing gently as the latter is lowered into the well produces a gurgling sound as the tube reaches the standing water. The depth at which the water is encountered can then be measured on the rod and recorded. More permanent wells have been made by lining deep post-holes with small tiles and filling in around them with gravel.

Fluctuations in Water-Table. — Much information can be gained regarding ground-water conditions at different seasons, by inquiry regarding domestic wells in a settled locality. The water-table may be local or general. The open substrata of a river valley may contain a general underflow closely related in elevation to the river, and somewhat related to the topography of the valley. A local water-table, due to seepage or irrigation may be encountered below a spring or over impervious strata. A temporary water-table occurs in the wet season over low areas. Such a water-table varies slightly with topography and is modified by the source of the water or by dense soil bodies. A tile-line or ravine below the level of the ground-water will tend to lower the water to a broad sloping plane on each side. The gradient of this water-plane may rise 1 foot in 100 feet in loam soil, and be nearly uniform; while in clay it may rise 1 foot in a lateral distance of 25 feet, and assume a curve with shorter radius closer to the tile. Surface evaporation and growth of plants tend to reduce the water-table, while irrigation or heavy rainfall cause it to rise.

Supply of Soil-Water. — The source of soil-water is precipi-

tation, and the initial amount depends upon the amount and distribution of rain. The drainage student should inform himself by means of water-supply papers issued by the Weather Bureau and the United States Geological Survey, as to the amount and distribution of rainfall and runoff in the localities in which he is interested.

Writers on climatology divide the rainfall year into three periods: first, a period of storage and excess; second, a period of growth; third, a period of replenishing. These begin about December 1, May 1, and September 1, respectively. From an agricultural standpoint they may vary somewhat with the locality.

In a wet climate excess water comes more directly from the sky. In irrigated lands it consists of water which has been stored and used for irrigation, and moves nearly horizontally in the form of seepage-water. In regions where the soil stores almost all the rainfall, as in the dry-farming sections, there may be no excess to drain off, so that no drainage problems develop.

In drainage operations we have to deal with excess rainfall, rather than with average rainfall. For example, at Corvallis, Oregon, where the mean annual precipitation is 42 inches, as much as 12 inches of rain may fall in one month, and as much as 2 inches in twenty-four hours, although there are but few days in the winter when more than 1 inch falls in twenty-four hours.

Drainage systems may be divided on the basis of effectiveness, into three classes. A first class drainage system disposes promptly of excess water resulting from mean maximum rains. A second class, or fairly thorough, land drainage system disposes of excess water except for a few days of the year. If drains in Willamette Valley have the capacity to handle ½ inch of runoff an acre, each twenty-four hours, they are adequate for agricultural purposes. A third class drainage system removes excess water within a reasonable time after clear weather sets in.

Effect of Drainage on Usable Water Capacity. — Usable soil-moisture occurs mainly in capillary form. It is not always

most abundant in the region of greatest rainfall, for the soil of the wet climate may dry and bake quickly after rains. A water-logged soil has a small amount of pore space, and does not retain moisture well in time of drought. When a soil is water-logged, the fine particles filter in between the coarser ones, and pore space is reduced to a minimum. The cementing materials that bind the particles in clusters are dissolved; the film attraction of soil-moisture is eliminated, and the soil-structure breaks down. Drainage removes the excess water, makes more room for usable water, and permits aeration and growth of feeding roots, which aid the formation of a good structure in the soil. In a drained soil, the improved soil-structure and the development of deep roots increase the water capacity; and a drained soil actually has more usable moisture and more resistance to drought than an undrained or wet soil.

Disposal of Surplus Water. — Excess water may be removed by surface runoff, percolation, evaporation, or transpiration.

1. *Runoff.* A large percentage of the excess rainfall may escape by runoff over the surface. The amount of runoff depends on depth of rainfall, on the season and the weather conditions, on topography, on the size, shape and location of the watershed, and on the amount of evaporation and transpiration taking place in plants. A greater proportion of the rain-water will run off when the soil is saturated, as in the winter and early spring. More will run off if the ground is frozen when the rain occurs. The amount of runoff also depends on the openness of the soil. The runoff from a large watershed in a humid climate varies from 1 to 3 or more second-feet a section.

2. *Percolation.* Free water percolates downward through the soil or seeps nearly horizontally through porous strata to lower levels. Writers classify the movements of percolating water according to the zones in which they take place. There are three such zones: first, the unsaturated zone, through which the water moves by percolation to the water-table; second, the surface zone of flow, which is represented by the shallow

water-table of the winter season, and shallow surface drains; third, the deeper zone of flow, which gives rise to deep wells, artesian wells, and springs.

The rate and amount of percolation depends, as already explained on soil-texture and structure. The presence of organic matter and lime aids in cementing soil particles into granules, while plant roots and burrowing animals leave passage ways for water. Shrinkage cracks in clay soils are effective at the beginning of the wet season. Changes in temperature affect the viscosity or ease of movement of water to some extent, and periods of low atmospheric pressure cause some increase in flow from springs or underdrains. Movement of soil-water to tile will be facilitated where soil conditions are favorable to a good rate of percolation, and where there is a greater head due to deep tiling or a steeper ground-water gradient.

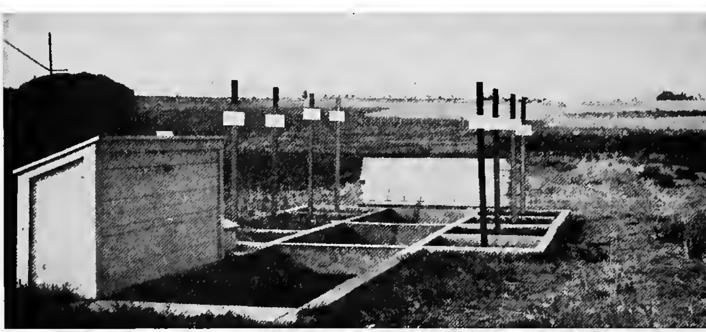

Fig. 8. Lysimeters or drainage gages, Umatilla Experiment Station.

Drainage gages or lysimeter tanks have been used in numerous places. Records have been obtained at Rothamsted, England, where undisturbed clay loam soil was enclosed in cemented tanks. The surface is kept free of all vegetation, so that measuring the drainage and subtracting it from the rainfall gives the evaporation by difference.

TABLE II. — RAINFALL, PERCOLATION, AND EVAPORATION AT ROTHAMSTED, ENGLAND

AVERAGE FOR 34 YEARS 1871 TO 1904

Months	Rainfall	Percolation through Soil			Per cent of Rainfall Percolating through Soil		
		20 inches	40 inches	60 inches	20 inches	40 inches	60 inches
January	2.32	1.82	2.05	1.96	78.5	88.4	84.5
February	1.97	1.42	1.57	1.48	72.2	80.0	75.2
March	1.83	0.87	1.02	0.95	47.6	55.6	52.0
April	1.89	0.50	0.57	0.53	26.5	30.0	28.0
May	2.11	0.49	0.55	0.50	23.2	26.1	23.6
June	2.36	0.63	0.65	0.62	24.0	27.6	26.3
July	2.73	0.69	0.70	0.65	25.3	25.6	23.8
August	2.67	0.62	0.62	0.58	23.2	23.2	21.7
September	2.52	0.88	0.83	0.76	35.0	32.8	30.0
October	3.20	1.85	1.84	1.68	57.8	57.5	52.5
November	2.86	2.11	2.18	2.04	76.7	76.3	72.4
December	2.52	2.02	2.15	2.04	80.3	85.4	81.0
Total per year	28.98	13.90	14.73	13.79	48.2	51.0	48.0
Total Evaporation by difference		15.08	14.25	15.19	51.8	49.0	52.0
Percolation for Years of Maximum and Minimum Rainfall							
Maximum (1903)	38.69	23.48	23.60	24.23	60.7	61.0	63.0
Minimum (1898)	20.49	7.32	7.90	7.69	35.7	38.5	37.6

The only drainage gages in the West are at the Branch Experiment Station, Hermiston, Oregon; and Superintendent H. K. Dean has supplied the following statement regarding the interesting work there.

"Study of soil-moisture in the rather sandy soil of the Umatilla Experiment Farm led to the installation of eight lysimeters for the purpose of tracing, more closely than was possible under field conditions, the relation of the moisture to the soil. The lysimeters are 3.3 feet square and contain soil to a depth of 6 feet. The soil was taken from the field

in 6-inch layers which were placed in their original order with their original density preserved as nearly as possible."

"The five soil types used are fine, medium, and course sand, silt and silt-loam. The medium sand grows (1) no crop, (2) soy beans in the summer and vetch in the winter, both of these being turned into the soil, (3) alfalfa and (4) alfalfa manured annually. The fine sand, coarse sand, silt, and silt-loam soils grow alfalfa without fertilization. The figures for 1915 are from May 22 to the end of the year; those for the new lysimeters in 1917 are from May 26 to the end of the year. The other figures are for the whole year, except those for 1918, which are to September 1. The application figures show the irrigation water applied plus the rainfall, which was 1.75 inches after installation in 1915, 9.87 inches in 1916, 8.86 inches in 1917 for the four original lysimeters, and 3.76 for the four new ones, and 3.60 inches for 1918 to September 1."

"The percolation from the medium sand lysimeters has been greatest each year from that not growing a crop, decreasing in the order mentioned from those growing soy beans and vetch, alfalfa, and alfalfa manured. The percolation from the lysimeters growing alfalfa has been lowest from the fine sand, greater from the medium sand, and greatest from the coarse sand. The silt and silt-loam soils have held all the water applied to them. The rate of percolation from the no-crop and from the soy bean and vetch lysimeters increases very rapidly, usually eight to ten hours after irrigation, and has reached a maximum flow within an hour after the first increase. From the maximum the rate gradually decreases until the next irrigation. The increased percolation after irrigation from the fine, medium, and coarse sand growing alfalfa comes twenty to twenty-four hours after irrigation and does not reach as high a rate as from the no-crop and from the soy bean and vetch lysimeters. The results show that there is a tendency for the percentage of percolation to decrease as the soils are cropped."

Maximum percolation, in first two, occurs eight to ten hours after irrigation; it increases rapidly for an hour or so then

gradually decreases till the next irrigation. Maximum percolation with alfalfa tank occurs twenty-two to twenty-four hours after irrigation.

TABLE III. — WATER APPLIED AND PERCOLATED FROM LYSIMETERS

Expressed in acre inches, six year average
Oregon Agricultural College and Branch Experiment Station, Umatilla, Oregon

Soil	Medium Sand				Fine Sand	Coarse Sand	Silt	Silt-Loam
Crop	No Crop	Soy Bean and Vetch	Alfalfa		Alfalfa			
Applied...	57.9	58.4	57.9	57.9	60.0	60.0	59.7	61.0
Percolated	39.6	27.7	12.9	10.8	7.72	14.9	None.	None.

Manure and continuous cropping to alfalfa is gradually decreasing percolation year by year.

3. *Evaporation* from the soil surface removes much of the rainfall, frequently, as with the Rothamsted Cylinders, as much as 52 per cent. Evaporation from a free water surface may vary from ½ inch to 2 inches a week, and, taken for the year, may exceed the annual depth of precipitation.

4. *Transpiration,* through growth on the land, transfers enormous quantities of water from the land into the atmosphere. The food of plants is taken up by the roots and carried, in dilute solution, to the leaves, where it is combined with the carbon dioxide of the air and forms the dry substance of the plant. The amount of water taken up in this way and given off again by the leaves averages several hundred pounds to each pound of dry matter produced. Transpiration usually eliminates several times as much water as evaporation. The two are generally measured together in determining the total water cost of dry matter, as given in Table IV for different crops and regions of the world.

5. *Artificial Control of Soil-Water.* — In the practise of ir-

rigation and dry-farming we aim to conserve the supply of soil-water, while in drainage we decrease the amount. Three practical means of decreasing the soil-water supply are cultivation, growth of plants and drainage.

Cultivation. — We can hasten evaporation by early spring cultivation of the soil, by increasing the air circulation, and leaving the soil with an uneven, ridged surface, which exposes a greater surface to evaporation. Cultivation may also increase the water capacity of the soil.

TABLE IV. — WATER COST OF DRY MATTER, DIFFERENT CROPS AND CLIMATES, EVAPO-TRANSPIRATION RATIO

Crop	King, Wisconsin	Widtsoe, Utah	Wollny, Germany	Powers, Western Oregon	Irrigation Investigations Eastern Oregon
Wheat	...	1017	...	...	871
Barley	464	801	774	514	623
Oats	504	871	665	...	680
Corn	270	552	233	548	787*x*
Clover	577	...	...	669	...
Alfalfa	...	1,096	...	848	990
Peas	447	1,118	416	...	852
Beets	...	760	...	520	909
Kale	...	...	...	937	...
Carrots	...	710	...	500	...
Beans	...	...	...	1,409	...
Potatoes	...	1,375	...	694	502
Cabbage	...	4,413	...	...	...
Onions	...	2,993	...	...	...
Marsh Grass	...	...	...	...	1,349*z*
Timothy	...	...	...	...	1,116
Timothy and Alsike Clover	...	...	...	...	560

Average of plots giving best use. All representative determinations.
x Southern Oregon.
z Tanks.

Growth of Plants. — Crops of any sort, weeds and cover-crops, will dry the soil by transpiration of water through the leaves. We take advantage of this in the early spring to take

out the excess water, and again in the fall when the cover-crop is planted in the orchard to take up the moisture and check growth, so that buds will be prepared for winter.

Drainage. — Drainage consists essentially in the direct removal of gravitational water from the root zone of the soil, by providing free passages for its percolation and flow. This is the chief means of artificially decreasing the supply of soil-water. It is simply a means of aiding gravity in removing the excess supply.

The outflow from the underdrained areas in the Central States, where fairly good drainage is provided, varies from $\frac{1}{4}$ to $\frac{3}{8}$ inches an acre for each twenty-four hours. Systematic measurements of outflow in western Oregon show that fairly good underdrainage would provide for the removal of $\frac{1}{3}$ to $\frac{1}{2}$ inch depth an acre each twenty-four hours.

Movement of Water into Drains. — Drain-tiles 1 or 2 feet long are laid through the soil in one continuous line, with such a grade that all water which finds its way into them will be carried by gravity to the lower end of the line and there discharged. The water enters the opening at the ends, or " joints," as they are called. The ends of the tiles are placed close together to prevent soil from entering, but room is left for water to enter.

When the drain is surrounded by saturated soil, water flows by gravity through the crevices in the ends of the tiles and passes off more or less rapidly according to the grade of the drain and the gradient of the water leading to the drain. Fresh soil-water takes the place of that removed by percolation, moving downward and laterally toward the drain, by the line of least resistance. The lateral distance through which the drain will relieve the soil of water is governed by the depth of drain and the resistance which the soil particles offer to the flow of water among them.

This tile-drainage process does not leave the soil without moisture, but simply removes the excess, or free water, and makes more room for the storage of capillary or usable water. It does not remove the free water from points below the level

of the drain. The free water which is removed may be due to seepage or directly to rainfall.

QUESTIONS

1. What different terms are used to refer to free water? Water-table?
2. What governs its movements?
3. To what extent can different crops tolerate free water?
4. How may the water-table be studied?
5. How may permanent observation wells be constructed?
6. What factors affect the topography of the water-table?
7. What conditions affect the prevalence and fluctuations of ground-water?
8. How does the effect of tile on the water-table in clay soil differ from its effect in sand?
9. What are the chief sources of rainfall and runoff data?
10. What are the different periods in the rainfall year?
11. What is meant by first-class and second-class drainage?
12. How does drainage increase the supply of usable soil-water?
13. In what different ways is excess rainfall disposed of?
14. Name the means of disposing of excess water artificially.
15. Explain how water enters tile.
16. How does water in the soil move to tile?
17. What can be done to aid the removal of excess water through a tile?

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CHAPTER V

TYPES OF DRAINS AND THEIR LOCATION

THE different kinds of soil-drainage may be classified as follows:

1. Natural Drainage.
   a. Through gravelly subsoil.
   b. Through surface runoff.
2. Artificial Drainage.
   a. Through open drains.
   b. Through underdrains.

Both surface drains and underdrains have their fields of usefulness.

Open Drains or Surface Drains. — These are essential for outlet ditches for large areas. They remove water from the surface and, to some extent, from the subsoil as well. The amount which they remove from the subsoil depends upon their depth and fall, and the amount of water in the channel. Surface drains are of value:

1. Where the volume to be removed is large
2. Where the water-table is near the surface, and the fall is so slight that it is impossible to place a drain below the surface
3. Where the drainage is temporary
4. As outlet ditches to receive tile discharge for large areas of flat land.

Disadvantages. — Open or surface drains have several disadvantages, as follows:

1. They are seldom of sufficient depth.
2. They are apt to have a small carrying capacity, due to the uneven grades, rough bottom and sides.
3. They are expensive to maintain.
4. They waste much land.

5. They greatly interfere with cultural operations.
6. They may be subject to serious erosion.
7. The banks become puddled, so that water from the surrounding land does not enter them readily.

Covered or Underdrains. — Underdrainage is the only complete and permanent form of drainage; underground drains make fields uniform with regard to moisture and facilitate farming operations. Many materials have been used for underdrains; but in recent years they have narrowed down to box-drains, cement drains, and clay tile drains, which are the commonest of all. Underdrainage will improve the soil where-ever there is not complete natural drainage. The extent to which underdrainage is justified depends on the value of the naturally drained surrounding upland and the net returns with and without drainage. More thorough drainage becomes desirable as the agriculture of a section becomes intensive and highly developed.

Relation of Surface Runs to Tile Systems. — To be most beneficial, drainage should be deep. It is practically impossible to over-drain a soil. While the open furrows or field ditches are of value for temporary drains, there are several objections to them. Surface runs, or permanent, shallow, open ditches in the field, should be made to follow fences or direct lines as much as possible. They may be kept in grass and used to remove the flood-water in case of extremely heavy storms, after which underdrains will remove the excess water from the subsoil.

The Parts of a Drain System may include the outlet, the head, a string of tile, a main or conducting drain and laterals or collecting drains, together with minor parts, which are discussed below.

The outlet for the lower end of the drain should be carefully located and have a free spillway. In laying out a drain system the outlet should be planned first. It is useless to improve a system unless a fair outlet can be secured.

The head of a drain is the up-stream end; this should not be confused with hydrostatic head.

A string of tile is a term used to designate a single line of tile that receives no branches. The *grade* is the finished tile-base at each station. *Gradient* is the slope of the tile-base and is expressed in fall per hundred feet.

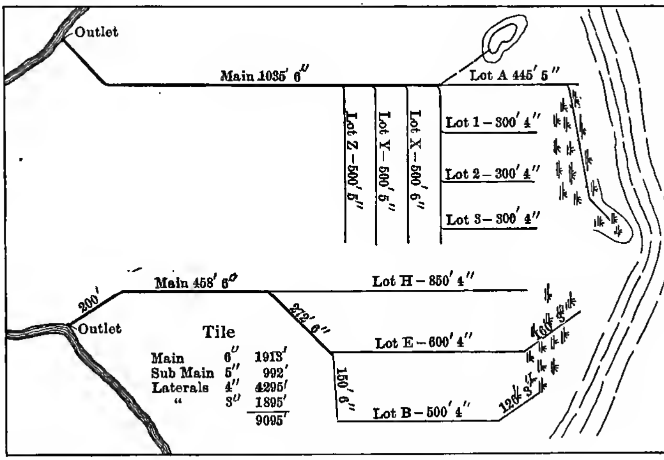

FIG. 9. The layout of a tile drainage system.

A cutoff, or intercepting drain, first used by Elkington in England in 1764, will frequently protect a flat from seeps above. It is a drain located so as to intercept seepage and cut the water off from lower land.

A main or conducting drain is a line of large tiles that carries the discharge from several laterals. It serves chiefly as a conducting drain and should be deeper than the laterals so that there may be free discharge and the larger tile may be protected from breakage.

Double mains are used where seeps appear on both sides of a broad flat, also where stream separates an open flat into two parts.

Sub-main is the term used for a smaller main discharging into a large main.

Laterals, or collecting drains, are usually single lines of tiling. If a short spur discharges into a lateral it can conveniently

be called a *sub-lateral.* Laterals are frequently arranged in parallel lines to form thorough systems. Laterals serve chiefly as collecting drains.

Lateral systems include natural or random systems, grouping systems, herring-bone systems, gridiron systems, and parallel systems.

Natural or random systems of drains follow the natural depressions in the land, and diverge like the frame of a tree.

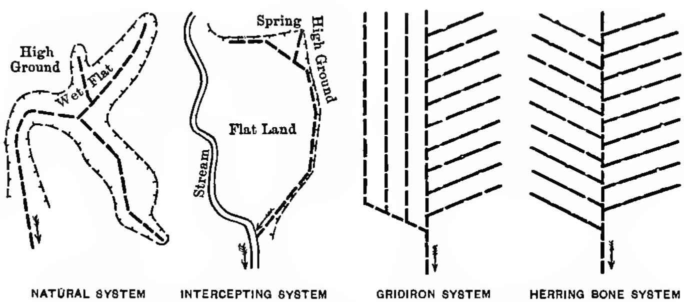

FIG. 10. Types of tile drainage systems.

The grouping system is similar to the natural system, except that a few short laterals may be provided in wet areas or ponds along the system. The natural and grouping systems are adapted to undulating land and to lands of only moderate value. Such systems may be used to give fairly thorough drainage for ordinary crops, where increase in yield from drainage will be sufficient to pay a good rate of interest on the investment.

The herring-bone system is used where the wet land lies in two planes, with the main drain passing down the center. The laterals enter from the side, at an angle to the main, and are arranged alternately.

The gridiron system usually contains two mains at angles to each other, with parallel laterals discharging into each main from a single side. Such a system is suitable where the wet area lies in planes not facing each other.

A parallel system of drains with a single main and long parallel laterals gives the least amount of double drainage. Long parallel laterals should be used in place of short ones, as there will be less expense for junctions. The parallel system of drainage is well adapted to flat land lying in one plane.

A drain system should be so designed that there will be long parallel lines with few junctions and but little double drainage. Where convenient, the laterals should run parallel to the fence line and to the dead furrows, so that supplemental surface drainage can be provided.

Vertical drainage is practical only where there is wet land with a tight subsoil and a coarse layer underneath, through

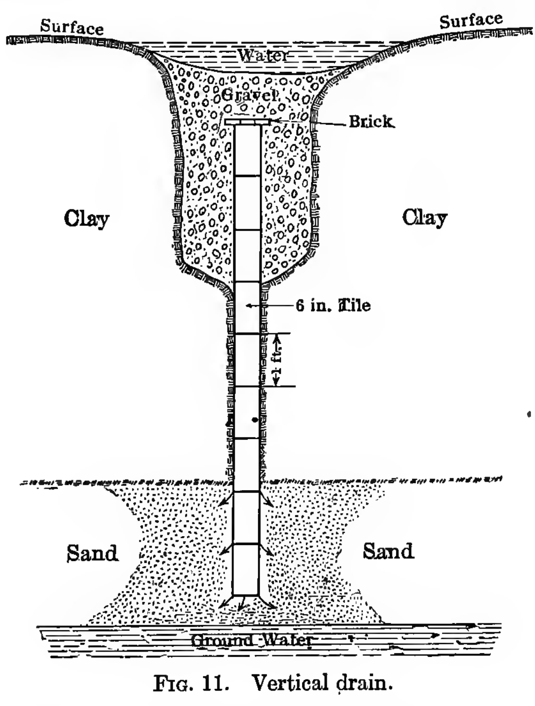

Fig. 11. Vertical drain.

which water will pass. A vertical drain can be made of small wells, below reach of the plow, lined with a column of drain

tiles surrounded with gravel and covered, making a permanent passageway down through the impervious layers.

The Location of Drains. — A carefully planned drain system may be installed in units, as time and means permit, and developed so as to afford more thorough drainage as general economic conditions come to justify a higher state of improvement.

In locating drains the following principles should be observed:

(1). Lay the mains along the lines of natural drainage, where water collects on account of the slope of the surface and subsurface strata. This should always be done, except where a cutoff drain will effect an economy.

(2). Lay the laterals along the lines of greatest slope. Otherwise, if the land is flat, the water may ooze out of the tile in the lower or sandier part of the course. Exceptions to this may at times prove economical or desirable in controlling silt or water-hammer.

(3). Use long parallel laterals in place of short ones, where possible.

(4). Make the lines straight or with gradual curves. They are easier to lay and to map, and offer less friction.

(5). Bring all the wet land under the influence of the tiles.

How to Determine Where Drainage is Needed. — Free water on the surface, or wet surface soil with the water-table near the surface at plowing time, is an indication of lack of natural drainage. It is desirable to see the land at the wettest season of the year. Flat land of fine texture in humid climates is likely to have imperfect drainage; and the topography and area of the tributary watershed, when considered with the amount and distribution of precipitation, will indicate the amount of flood-water to be contended with. Where wet land is in a clean cultivated state or free from vegetation, the light color of the surface soil in wet, low places will be apparent.

Borings with the soil-auger will reveal the presence of ground-water, and a light gray or mottled subsoil will indicate an unaerated, water-logged condition the greater part of the year. Gullying or erosion may also indicate need of drainage.

Vegetation common to wet farm lands includes sorrel, red-top, velvet-grass, buttercups; forget-me-nots, and docks. On muck lands, wire-grass, sedges, tussocks, mint, wild cabbage, cat-tail, and perhaps willows and spruce may occur; bull-rushes may be found on medium or deep peat. On alkali land, salt-grass, foxtail, and grease-wood are commonly found, while cat-tails and water-loving grasses may develop with water-logging in irrigated sections. The presence of tall rye-grass or buck-grass indicates slacked subsoil and free water within a few feet at certain seasons in the arid region, while rushes commonly mark the points of seepage in wet climates. Yellowing of crops and rank growth of fruit trees, with subsequent winter killing, are often related to poor drainage.

Location of Drains with the Auger and Level

When designing a drain system, it is best to begin at the outlet and determine the depth at which the drain can be placed and still have a free discharge. The level will be useful here. All leveling data should be referred to a permanent bench-mark. As the examination proceeds upstream test pits should be made at frequent intervals with a posthole-auger or soil-auger and the character of the subsoil observed with a view to placing the drain at the depth of the most free-working soil.

The occurrence of underground water should be noted, and any seepage water traced to its source, to determine whether it appears over or under any hard layers of soil. The drains can then be designed so as to intercept this water and convey it away as directly as possible. A few range poles or stakes should be set up at various points in the field through which it is desired to have the survey for the drains pass. Preliminary levels may be taken to decide on the best possible outlet and determine the lay of the land. A series of readings taken

around or across the field in both directions will usually disclose the variations in a fairly flat piece of land. A map of a wet farm having irregular topography would be very desirable. Because drainage is a rather expensive improvement, and some soils, like the "white land," are rather slow to respond to it, the drains should be located, and the land handled after drainage, so as to loosen up the soil and facilitate the entrance of water into the tile, thus making the enterprise thoroughly profitable and successful.

The use of catch-basins, the practise of allowing the subsoil to crumble before filling the trench, and the use of soda over the tile are all means of aiding the water to enter the tile.

The success of a drain system depends largely upon its proper location. It is better to see the land both in the wet season and in the dry season before designing the drain; but if only one examination can be made, the time of year that cultivation begins is the best time to locate land that is affected by surplus water.

QUESTIONS

1. Under what conditions may a surface-run be used, and how is it designed?
2. Define outlet, head, cutoff, grade, gradient, collecting drain, conducting drain, submain.
3. Describe the natural or random system of tile and explain where it should be used.
4. Where is the herring-bone system suitable?
5. What are the advantages of the parallel system of drains?
6. Under what conditions should thorough systems of tiling be used?
7. Describe the vertical drain and explain where it may be employed.
8. State the principles to be observed in locating drains.
9. What soil conditions indicate need of drainage?
10. What kind of vegetation occurs on wet marsh lands? On wet farm-land?
11. What are the first indications of water-logging of alkali?
12. What points should be determined with the soil-auger in locating drains?
13. In designing drains, what data about the land should be obtained?
14. Explain the procedure for designing and estimating the drainage requirement of a wet field.

15. What can be done to facilitate entrance of water into tile?

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CHAPTER VI

MATERIALS FOR COVERED DRAINS

A VARIETY of methods and materials, including brush, poles and stones, have been used in the past for the construction of covered drains. Most of these were effective, but so crude that the modern cement and clay pipes have entirely displaced them. In the earlier attempts at drainage, however, clay and cement tile were, of course, not available and the use of other materials was necessary. Practise is now largely confined to the use of clay and cement tile.

The pole-drain has been used in regions where timber was plentiful and other material scarce. Three poles were placed in the trench, the third on top of the other two in such a way as to leave a small space for the water to flow between the three.

Box-Drains. — The box-drain is a type of drain still in use where timber is cheap and where the boxes can be kept moist throughout the year. It is frequently used in draining alkali lands, where the action of the alkali would destroy cement tile. It is also used in peat lands, where the settlement of thepeat would throw the short tiles out of line. The life of such a drain is reasonably long if it is always wet; but if subjected to alternate wet and dry conditions the boxes rot out inthree or four years. Such drains must be so constructed that their integrity of shape does not depend on nails, as nails rust away

FIG. 12. Wooden box drains used at Mallet, Oregon.

in a short time, whereupon the box, if not correctly constructed, will collapse. Neither open-bottom boxes nor triangular boxes should be used for drains. Both of these types have a tendency to choke.

The most modern material for underdrains is tile. It may be made either of concrete or of clay.

Cement Tile. — During the last twenty-five years, cement tiles have been used more or less throughout the United States. They have competed successfully with clay tile in sections where there was a scarcity of suitable clay or a lack of transportation facilities. They are now being used in every section where drain-tiles are required.

In order to prevent destruction by frost, the tiles should be as dense, or water-tight, as possible. The concrete should therefore be mixed wet, not dry. The proportions should be 1 part of cement to $3\frac{1}{2}$ parts of sand well mixed. There is a tendency among farmers to construct their own tiles, using leaner mixtures; but this invariably results in failures, which have contributed much to the unpopularity of this kind of tile. The lean mixtures cannot be recommended, and cement tile construction should be left to experienced makers. If proper precautions are observed in the making, cement tiles will prove satisfactory everywhere except in the presence of certain alkali salts. In irrigated regions the character of the alkali and its effect on cement tile should be determined before using such tile.

It is rather difficult to determine by inspection that a cement tile is faulty. When the cement is good and the materials well mixed and allowed to set properly, the tile is likely to be durable. The following rules may aid in detecting defective cement tile.

1. The more cement used in making tiles the lighter in color they will be. A dark-colored cement tile, or one which seems light in weight for its size, should be looked on with suspicion.
2. Cement tiles fail under slightly less load than clay

tiles. To test the strength of a 5 to 8 inch cement tile, jump on it as heavily as possible. If you cannot break it you are fairly safe in using it. A small cement tile should hold up a load of 800 to 1000 pounds to each foot of length, without support on the sides.

3. Try crumbling off the edges or corners, with the fingers. If it crumbles easily the tile should be rejected as being made of poor materials or lean mixture.
4. Cement tile will not give as sharp a ring, when rapped with a piece of steel, as clay tile; but once one is accustomed to the sound it is easy to detect defective cement tile by this method.
5. Weigh a tile; then soak it twenty-four hours under water. Weigh again, and if it has absorbed more than 9 per cent, by weight of water, it should be rejected. Good cement tile will absorb between 6 and 9 per cent water.

Effect of Alkali on Cement Tile. — Laboratory experiments show that alkali will disintegrate concrete in two ways. First, if the concrete is somewhat porous, and it is constantly supplied with a salt solution which is permitted to crystallize in the pores, the expansion of the salt crystals during the process of crystallization will exert enough mechanical force to crack the concrete. Second, if hydrated cement is brought into intimate contact with certain sulphate or chloride solutions, the uncarbonated lime of the cement is subjected to rapid solution, with a resulting decomposition of the cement.

The Bureau of Standards, in coöperation with the Reclamation Service and the Portland Cement Association, has for the past few years been investigating the effect of alkali on concrete drain tile in the arid sections of the West. The investigations covered 9000 different tiles of twenty different varieties, and involved their shipment to various Government

projects in the alkali regions of the West, also to fresh water projects in Minnesota and Missouri.

These experiments show that the presence of alkali in the form of sulphate of sodium and magnesium in any considerable amounts, has a disintegrating effect on concrete, greatly reducing its strength and causing it to crumble. This is particularly true of mixtures leaner than 1 part cement to 3 parts sand, while mixtures richer than 1 to 3 are but slightly affected. Common salt (sodium chloride) and sodium carbonate do not seriously injure concrete tile.

Concrete tile that is to be used in alkali soil should be made of selected and tested materials, so proportioned as to produce a very dense concrete. As small an amount of mixing water should be used as will allow the proper placing of materials. Unless such precautions are taken there will be insufficient resistance to alkali action. The Bureau of Standards has drawn the following conclusions regarding the use of cement tile in soils or waters containing more than 0.1 per cent alkali.

1. The use of cement tile in alkali soils is experimental.
2. Tiles which are porous because of lean mixtures or relatively dry consistencies are subject to disintegration.
3. Some dense tiles are, under certain conditions, subject to surface disintegration.
4. Disintegration is manifested by physical disruption, caused by expansion resulting from crystallization of salts in the pores, and also by softening, resulting from chemical action of the solution with the constituents of the cement.
5. Indications are that the greater the quantities of sulphates and magnesium present and the greater the total concentration of salts, the greater will be the disintegration.
6. Rich tiles, as commonly made, are subject to disintegration when exposed to soils or water containing 0.1 per cent or more of alkali salts.

7. Hand-tamped tiles are not equal in quality to machine-made cement tiles and do not resist alkali as well.
8. Steam-cured tiles show no greater resistance to alkali action than tiles that are cured by systematic sprinkling.
9. Tiles made of sand-cement have less alkali resisting powers than those made of Portland cement.
10. Neither tar-coating nor cement grout is effective in preventing the absorption of alkali salts from the soil.
11. The introduction of ferrous sulphate into the cement as a waterproofing agent is found to be of no advantage.

Failures and Requirements. — Many costly mistakes have been made in the development of cement tiles. These occasional failures are invariably due to one of three causes: (1) poor materials, (2) too lean a mixture, (3) poor workmanship in mixing and tamping the tile.

A mixture of 1 part good Portland cement to 3 parts good clean sand, well mixed and moulded wet, produces a good tile. The walls of the tile should be thicker than those of clay tile. In curing, care should be taken not to dry out too fast. The green tile should be kept moist for several days by sprinkling, to prevent cracking.

A small cement tile should hold up a load of 800 to 1000 pounds to each foot length, without support on the sides of the tile.

Clay Tiles. — Three classes of clay tiles are made : (1) common clay, or shale tile, (2) salt glazed tile, and (3) vitrified tile. Common red clay tiles are made from ordinary brick-clay, which may be found in every locality where drainage is necessary. No special kind of clay is essential to the making of good tile. The general quality essential to its manufacture is that the clay be sufficiently plastic when wet to be forced through a die and molded into a cylinder without serious

cracking or checking. Many kinds of clay possess these characteristics, and it is seldom that such clays do not make good drain tiles. Surface clays are sometimes added to the deeper clays to control shrinkage, color, and density of the tile. Deeper clays, such as may be found at a depth of 10 to 12 feet, may not be satisfactory when used alone. They are apt to shrink and warp or to develop shelly structure (caused by the auger of the clay-machine) which is called "auger" or "laminated" structure. This defect is corrected by the addition of sand or sand-bearing surface clay. Good tiles are practically cylindrical and give a clear, sharp ring when struck with a piece of metal. Since the clay shrinks in burning, the length and thickness of the walls, and the diameter may vary somewhat with the degree of burning. The over-burned tiles will be smaller in dimensions. The well-burned pieces are usually 1 foot long. For smaller tiles, except in the case of the hardest-burned, there will be a slight overrun which will about compensate for breakage in transportation.

Fig. 13. Shale tile plant, Sheffield, Illinois.

Fig. 14. Shale pit supplying plant shown in Fig. 13.

Salt glazed tiles are made by treating the fire, with salt, thus causing chlorine fumes which form a flux with the silica, giving the tile a smooth surface.

Vitrified tiles are usually made of ground shale or high-grade shale clay mixed with common clay. These stand a higher heat

and will fuse and form a hard mass of greater strength and less absorption qualities than the common clay tiles. Over-burning this ware makes it weak and brittle. Vitrified tiles are usually dark brown in color. They are always good; and, if the price is the same, they are preferable to ordinary clay tiles. If hard-burned, first-quality common clay tile can be obtained, however, they are just as good for farm drainage purposes. Vitrified pipes are especially useful at the outlet when it is exposed to frost. Clay tiles, when exposed to the air in freezing and thawing weather, are likely to disintegrate; but when buried below the frost line they are not so affected and are permanent.

Standards and Tests. — The quality of vitrified tiles varies greatly. Tests show that over-burning will make the material brittle and impair its strength. Care should be taken to select tiles of medium burn for deep trenches, as these tiles are tougher and stronger than the brittle, hard-burned tiles. Tile-layers should be instructed to throw out all tiles that are soft, cracked, or ill-shaped. Medium tiles are usually straight. All tiles warp more or less in burning, but badly warped pieces should be thrown out.

FIG. 15. Styles and forms of shale tile.

Second-class sewer-pipes may frequently be obtained from the manufacturers at prices which warrant their use for drainage-tiles. If the worst pieces are rejected, they make excellent tiles for use where the ground is soft, as the bell-and-spigot joint aids in preserving the alignment, especially, if the joints are cemented in the worst places.

Inspection of Clay Tiles. — All clay drain-tiles should be thoroughly inspected before laying. They should be hard-

burned, true to shape, and with full rated dimensions both as to diameter and length, and should give a clear metallic ring when struck with a piece of steel. A cracked tile can easily be detected by the absence of this ring. One crack, not to exceed 20 per cent of the length of the tile may be allowed, but no more.

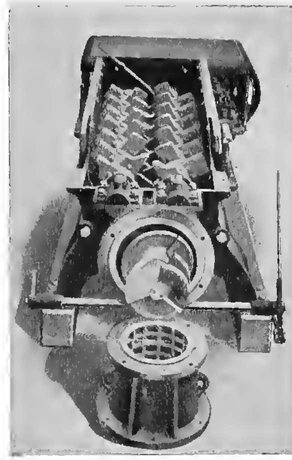

Fig. 16. Tile machine. This machine mixes the clay and forces it through a die onto the table shown in Fig. 17.

Hard-burned tiles are usually the best. Hardness or density is indicated by the cherry-red color, which is generally preferred, since it indicates thorough burning and absence of impurities in the clay. The porosity of the tiles may be tested by the water-absorption test, which is made by weighing the tiles dry, soaking them in water for twenty-four hours, and weighing them again on removal from the water. The grade of tiles can be determined as follows:

Soft tile	absorbs	10 per cent	by weight	in twenty-four	hours
Hard-burned tile	"	8	"	"	"
Vitrified tile	"	6	"	"	"
Glazed tile	"	5	"	"	"

The thickness of the tiles is also important, from the standpoint of strength and for making good joints.

The weight of a 4-inch tile should not be less than 6 pounds, that of a 5-inch tile, 8 pounds, and that of a 6-inch tile, 11 pounds, for each foot of length. In the larger sizes, if the difference between the greatest and the smallest diameters exceeds the thickness of the shell, the pieces should be thrown out.

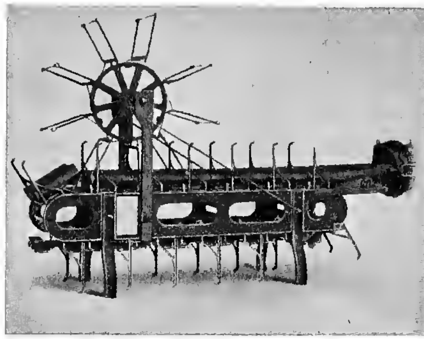

Fig. 17. Tile table.

Other Simple Tests for Clay Tiles. — Breaking Tests: Clay tiles should have a bearing strength according to the following table, taken from the Yearbook of the American Society for Testing Materials:

STANDARD DRAIN-TILE

Internal Diameter of tile in.	Minimum Average Ordinary Supporting Strength, pounds per linear foot	Maximum Average Absorption by Standard Boiling Test, Per Cent		
		Shale and Fire-Clay tile	Surface-Clay Tile	Concrete Tile
4	1200	9	13	11
6	1200	9	13	11
8	1200	9	13	11
10	1200	9	13	11
12	1200	9	13	11
14	1200	9	13	11
16	1300	9	13	11
18	1400	9	13	11
20	1500	9	13	11
22	1600	9	13	11
24	1700	9	13	11
26	1800	9	13	11
28	1900	9	13	11
30	2000	9	13	11
32	2100	9	13	11
34	2200	9	13	11
36	2300	9	13	11
38	2400	9	13	11
40	2500	9	13	11
42	2600	9	13	11

A simple field testing apparatus can be arranged as follows for testing ordinary farm tile: Take a pole 12 feet long and fasten one end, with a chain or bolt, to a post or sapling. Place the tile to be tested between two boxes of sand, one above the other, the inside dimensions of the boxes being an inch or two greater than the outside dimensions of the tile. Place the center of the boxes $1\frac{1}{2}$ feet from the fixed end of the lever if the apparatus is to be used by a 180-pound man, or 2 feet for a 200-pound man. Bring the lever down on the box and throw the man's entire weight on the outer end of the lever, 10 feet from the fixed end. This will put a pressure of 1000 pounds on the tile. If the strength of the tile is equal to this test it is sufficient for practical purposes. Several tiles should be tried before a decision is reached. If there is a large percentage of failures, the lot should be rejected.

The American Society for Testing Materials give the following specifications for arranging the sand boxes for tile tests: Where sand bearings are used, each specimen, shall be accurately marked (around the circumference) in quarters, with pencil or crayon, prior to the test. Specimens shall be bedded above and below in the sand for $\frac{1}{4}$ the circumference of the pipe, measured on the middle line of the shell. The depth of the bedding at the thinnest points above and below the pipe shall be equal to $\frac{1}{4}$ the diameter of the pipe, measured between the middle lines of the pipe walls.

The sand used shall be clean sand which shall pass a No. 4 screen. The top bearing-frame shall not be allowed to come in contact with the pipe or with the test-load. The upper surface of the sand in the top bearing shall be carefully struck level with a straight edge and shall be carefully covered with a heavy rigid top bearing plate, with lower surface a true plane made of heavy timbers or other rigid material capable of uniformly distributing the test load without appreciable bending.

The frames should be dressed on all interior surfaces, and no frame should come into contact with the specimen during the test. Strips of cloth may be used on the lower edge of

the upper frame to prevent loss of the sand during the test. The load must be applied at the exact center of the upper bearing, in such a way as to allow free movement of the bearing in either direction. This may be accomplished with two rollers at right angles, one on top of the other.

Absorption Test. — Weigh a tile, then immerse it in water for twenty-four hours and weigh it again. If the gain in weight exceeds 9 per cent, a soft, porous tile is indicated. Such tile should not be used, especially above the frost line.

Durability of Tile. — In any place except in alkali soils containing sulphates of sodium and magnesium, there is little choice between cement and clay tile. With the above exception, one is as durable as the other. The small-sized clay tiles usually can be made to better advantage in competition with cement than can the large sizes.

QUESTIONS

1. Of what materials were the earliest drains constructed? What may be said of their durability?
2. Describe the brush, stone and pole-drains.
3. What is the objection to the use of box-drains?
4. Why are they constructed without nails?
5. Why should cement tiles be made of very dense mixture?
6. What does a light color in cement tiles indicate?
7. How does the breaking-strength of cement tile compare with that of clay tile? Describe a good practical field test for breaking-strength.
8. How much water may a good cement tile absorb in the twenty-four hour soaking test?
9. What alkalies are most apt to disintegrate cement tile?
10. How is the disintegration accomplished by these alkalies?
11. What kind of cement mixture would you use to prevent such disintegration?
12. What is the relative value of sand cement and Portland cement tile for alkali drainage?
13. What was the shape of the first clay tile?
14. Why was the shape abandoned?
15. What are the essential qualities of good tile-clay?
16. How may laminated structure of clay tile be avoided?
17. What are the vitrified tiles? Of what are they made?
18. What can you say of the uniformity of quality in clay tiles?

19. What are the qualities of clay tiles upon which the inspector must insist?

20. Describe the simpler tests applied to determine the quality of clay tiles.

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CHAPTER VII

DEPTH AND FREQUENCY OF TILES

THE depth, frequency, and size of tiles are subjects which are closely related and are among the largest questions to be decided in tile-drainage. These factors can be definitely determined only after consideration of the character of soil and subsoil, the amounts and distribution of rainfall, topography of the surface and the amount of runoff, the crops to be grown, prevalence of underground water and the grade obtainable, and area to be drained. The tile system should always be arranged with reference to these considerations.

Depth for Drains depends upon the kind of crop to be raised and the nature of the soil. King states that the depth must be

FIG. 18. Profile of alkali soil and water tables, Malheur Valley.

such that water can get to the tiles before it seriously injures the crop. If water is kept moving and contains some air, the crops are less liable to injury. Some crops are more tolerant of an excess of water than others. The drains should be in the water to be removed and below the bulk of the roots. Deeper drains will in general be necessary in orchards and with deep-rooting crops.

The soil also affects the depth for drains. In porous soils' drains can be placed at a good depth, perhaps 3½ or 4 feet. This permits deeper drainage, and the draining of a greater

area by a single line of tiles. In sand, it is not generally desirable to lower the water-table as far as plant roots extend. In some of our peat soils, sub-irrigation takes place, moisture being drawn upward by capillarity and distributed through the soil at an elevation of 30 to 36 inches above the water-table. In porous soils, drains attain their full efficiency almost at once; but in dense clay the efficiency increases as the soil becomes granulated and the drain system becomes effective. Some silt is washed out through the tiles, and after a few years tiny streamlets are formed leading to the joints in the tiles. In clay, in order to dispose of the water promptly, the drains must be fairly near the surface and used chiefly to dispose of water in the surface layer. Tiles should be placed on the boundary between sand and clay, if there is a change in soil texture at any reasonable depth. This allows water to move to the tiles through the sand, along the line of least resistance. The proper depths for different soil types and conditions are further discussed below.

Frequency of Drains. — The distance between drains is closely related to the depth and is affected by about the same conditions. The relation of depth to frequency in a porous soil is fairly definite. For example, twenty-four hours after a sandy soil has been saturated by rain, a study of the water-table extending back at right angles to the tile line will show it to have an even grade toward the tile. At a distance of 50 feet back, the elevation of the water may be 1 foot above the elevation of the tile. Under this condition, with porous soils, tiles placed 1 foot deeper should lower the water-table 1 foot farther from the soil surface at the 50-foot point, and should pull the water-table down to an elevation of 2 feet above the level of the tile, at a distance of 100 feet back. In a clay soil this grade would run in an arc instead of a straight line; at a distance of perhaps 25 feet from the tile, the water-table might be 2 feet above the level of the water in the tile, twenty-four hours after a heavy rainfall. The soil texture, therefore, affects the distance which may be left between drains. Fine-grained or heavy soil offers a great deal of friction or resistance to the

movement of water, and such soils require frequent laterals for thorough drainage.

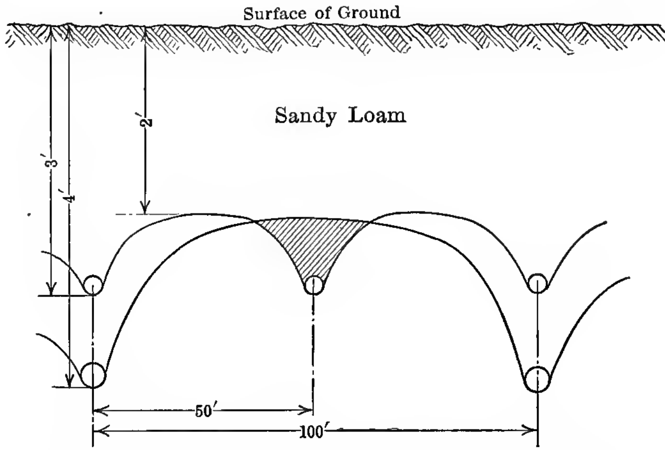

FIG. 19. The influence of the spacing and the depth of tile drains upon ground water.

The rainfall and the time within which it is necessary to remove it also affect the allowable distance between drains; and, if water must be removed in a short time from the heavy soil, drains must necessarily be placed close together and near the surface.

Experiments Relating to Depth for Drains. — For several years hundreds of miniature wells have been maintained during the wet season in typical drained and undrained "white land" areas, to show the fluctuations in the water-table and the effect of the soil layers and tile lines upon the position of the ground-water. In typical "white land" there is usually a heavy clay sub-surface, beginning at a depth of 12 or 15 inches and extending to a depth of 30 or 36 inches below the surface of the ground. The soil then changes to a yellowish, silty clay loam, which is usually somewhat mottled, showing brown spots where the soil is set with larger amounts of iron and clay. From these studies, it is found that in the flat areas of "white land" tile placed at a depth of about 33 inches will generally

be below the blue clay sub-surface and in the most porous layer to be encountered. Placed at this depth, tile-*drains have lowered the water-table* sufficiently for cultivation, or about 2½ feet, while water still stood on the surface of adjoining land of the same character.

In two drainage systems on the Experiment Station farm at Corvallis, where the laterals average about 3 feet in depth,

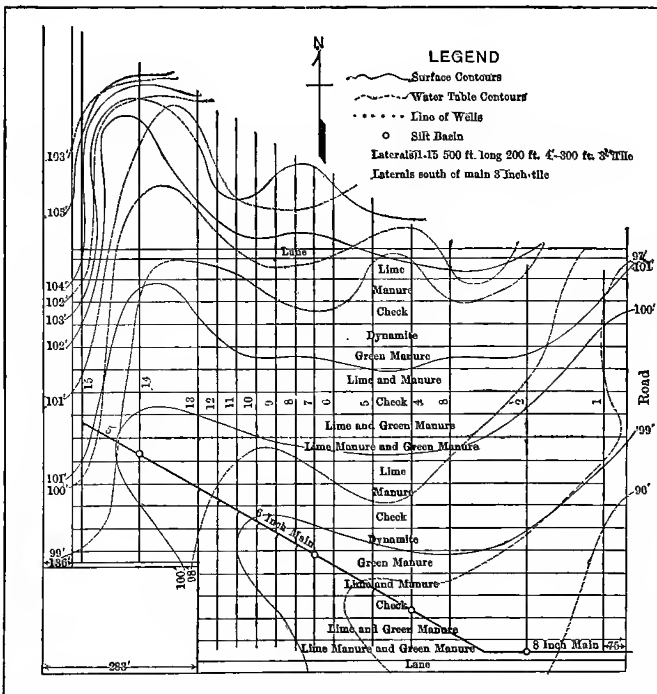

FIG. 20. Plan of drainage plots at Oregon Agricultural College.

as much as ½ inch of rainfall an acre is frequently discharged in twenty-four hours. One of these drainage systems has been in operation for twenty-five years, and the other for two years. *The structure of this land shows gradual improvement since the installation of drainage.* Observations of the discharge from

other drainage systems on College land, where the tile laterals are 40 to 42 inches in depth, show that these drains do not discharge more than $\frac{1}{4}$ to $\frac{1}{3}$ inch an acre in twenty-four hours, under the same soil and weather conditions that cause a $\frac{1}{2}$-inch runoff from the shallower drains. A drain system capable of removing $\frac{1}{2}$ inch to the acre in twenty-four hours is regarded as fairly good for Willamette Valley conditions.

A series of lateral drains was installed in 1908 on a piece of "white land" near Albany, Oregon, by the United States Office of Drainage Investigations, the laterals being placed the same distance apart, which was 60 feet. The depth varied from $2\frac{1}{2}$ to $4\frac{1}{2}$ feet.

Results of Experiments Relating to Depth. — Frequent observations of the water-table and the discharge from these drains show that no advantage has been secured from drains deeper than the average in this type of soil. The present owner of this land states that he has been unable to discover any difference in crop yields or conditions in favor of the deeper drains. A study of water-table conditions in the vicinity of these drains indicates that, for at least two weeks after heavy precipitation, drains laid $4\frac{1}{2}$ feet deep are less effective with this soil than those laid at a depth of 33 to 36 inches. This is probably because the so-called "white land" has a rather impervious sub-surface layer, and the most friable stratum that can be found underneath occurs at depths of about 33 inches below the surface. The water that falls on such land and accumulates there comes from heavy rainfall rather than seepage, and does not find its way into the deep drains as readily as into those of an average depth.

A new experimental drainage system, having a deep outlet near at hand, is being installed on the 3-acre piece of "white land" on the Experiment Station farm near Corvallis, Oregon; and a further study is being made here of the effect of drains at different depths. The soil has been found to be fairly uniform. Manholes are being constructed, so that the runoff from laterals of different depths can be measured. In one section of this experiment the relative values of straw and

gravel, placed over the tile lines to aid percolation, are being studied. The accompanying map shows the topography, soil types, and drainage system. The tile is being installed by College classes. The northern part of the field serves temporarily as an undrained check.

Studies of this tract have been made by the writer for the past four years, and it has been found that the water-table is affected 25 to 30 feet back from the tile, twenty-four hours after rains have caused saturation, or rise of the water-table to the surface. Where the laterals are a greater distance apart, water frequently stands in the dead furrows for several days at a time.

The Iowa Engineering Experiment Station, after studies of the operation of representative tile systems in that state, recommends that tile be placed, in Iowa, at a depth of about 4 feet, unless the subsoil is very impervious, when a $3\frac{1}{2}$-foot depth may possibly be used. The land so drained can usually be passed over dry-shod.

Experiments on Heavy Soil. — A field of "white land" on the Experiment Station at Corvallis was provided in 1914 with an experimental drainage system in which the laterals were installed at a depth of about 3 feet, at distances of 25, 50, 75, and 100 feet apart. The surface and water-table topography, as well as the arrangement of tile-drains and the subsequent surface treatments are shown in the accompanying figure.

Experiments Relating to Distance Between Drains. — For several seasons, wells have been maintained at regular intervals over this area during the early spring season. Before drainage, the water-table was within a few inches of the surface during March and April, while, in the year following drainage, the water-table in the more thoroughly drained part of the field averaged about $2\frac{1}{2}$ feet below the surface at the corresponding season.

During the past two wet seasons the rate of discharge from guarded laterals representing each spacing studied has been measured at regular intervals in wet weather. These laterals

are each 500 feet long. A 25-foot lateral drains approximately $\frac{1}{3}$ acre, while the 50-foot laterals drain $\frac{2}{3}$ acre each, and so on. Table VI gives the rate of discharge for each spacing, expressed in acre-inches runoff an acre in twenty-four hours, and also the crop yields to the acre.

TABLE VI.—DISCHARGE FROM LATERALS PLACED DIFFERENT DISTANCES APART

Distance between laterals (feet)	Maximum dis-charge acre-ins. an acre per 24 hrs.	Mean dis-charge acre-ins. an acre per 24 hrs.	Mean Daily rain previous two days (ins.)	Daily outflow (per-centage)	No. Tiles to the acre	Mean acre-ins. dis-charge per 1000′ tiles 24 hrs.	Yield barley per acre 1915 (bush-els)
25.......	1.20	.48	0.60	80	1742	.96	33.73
50.......	1.35	.55	0.06	92	872	1.10	29.90
75.......	.80	.33	0.60	55	586	.66	27.90
100.......	.90	.32	0.60	53	436	.64	20.35

Winter barley on undrained land, under similar conditions, yielded 16 or 18 bushels to the acre, whereas marked increases are shown for this crop after drainage. Laterals removed the excess water more promptly than was anticipated, considering the heavy nature of the soil. Little outflow from laterals occurred preceding the maximum runoff, on March 26. Rainfall for March 25 was 1.28 inches; and for March 26, the maximum discharge was observed at the close of the wettest day of the year, to be 1.89 inches. Dry weather followed and laterals had nearly ceased discharging by March 28.

These experiments are being continued, and equipment is to be secured that will enable the investigators to keep more nearly continuous records of rainfall and runoff.

The effect upon the water-table of these tile lines has been studied for two seasons. Tile wells surrounded with coarse sand are used for these observations.

The results so far obtained indicate that the 25-foot spacing

handles excess water most quickly. The 50-foot spacing gives the highest efficiency for each 100 feet of tile employed, while the 100-foot spacing continues to drain after the laterals have ceased to discharge into it at the manholes where measurements are taken. It is believed that, in this soil, deeper drains will act more slowly, but will continue to drain for longer periods of time than will drains of an average depth. The soil is dry enough for tillage and seeding operations, however, a few days after the water-table has been lowered to an average depth of 30 inches below the surface, a reduction which takes place promptly with laterals placed as in this system.

Soil-moisture determinations made on drained and undrained "white land" show as much as 4 per cent more moisture in drained land in dry weather.

About a year ago, a list of questions was sent out to farmers who had installed drainage systems. Replies from some fifty farmers covering their experience with approximately 100 miles of tile in the Willamette Valley, show that the average depth of mains is approximately 4 feet. The average depth recommended in the replies is 3 feet. The laterals range from 4 to 10 rods apart, the average distance reported being 83 feet. An average distance of 4 rods between laterals is recommended; though 50 feet was a common reply. Practically all of these tile systems were declared successful by the landowners.

The Iowa Engineering Experiment Station, after thorough investigation, reports that laterals spaced 50 feet to 100 feet apart, in ordinary soils of that state, will give adequate drainage for field crops. It is not considered profitable to place them more than 75 feet apart. A distance of 33 or 50 feet is recommended for heavy soils or intensive crops, while for unusually open soils a distance of 150 feet is regarded as sufficient.

Laterals for Other Loam Soils. — Loam in Western Oregon usually requires a random or natural system of drains, larger tiles being placed at the natural depressions in the land. These laterals should be of good capacity and good depth, perhaps $3\frac{1}{2}$ feet for smaller sizes and 4 feet for the 8 to 12 inch sizes. Gener-

ally the soil will be a little heavy in these draws, but the drains can be placed deeper if occasional catch-basins are installed. Drains placed in natural depressions should be deep enough to receive the discharge of any laterals that may need to be installed later. Flat, wet areas of brown loam require thorough drainage, and can be drained fairly well with tile lines six rods apart. Gray-brown silt loam or " near-white-land," in this valley, requires more thorough drainage; under average conditions tiles 3 feet deep every 5 rods should provide good drainage for this rather wet land.

Laterals for heavy clay or " black sticky " soil can be greatly improved by the use of protecting drains to collect the water before it gets into the sticky area. It is very doubtful whether it would pay at present to provide the thorough, expensive underdrainage necessary for the highest development of this land. Much soil of this type is underlain with a rather porous layer of sand at a depth of about 4 feet, and, by the time the surface water is disposed of, no water-table is to be found in the subsoil and the land is ready for cultivation, which must be performed while the ground is still rather damp.

Field drains for red hill soils are usually for the purpose of controlling erosion or to collect seepage water from springy areas. If the land to be drained is used for an orchard, tile lines should be located between the tree rows, following spaces diagonally, if necessary, and avoiding the trees as much as possible. Study of the subsoil conditions will usually reveal hard layers of shale or clay which are responsible for crowding the water out to the surface. Sometimes intercepting or collecting drains, with the aid of relief wells, will be effective in drying up seepage from these hill lands. The cutoff for protecting drains should usually pass along the slope, with a fall of at least 3 to 6 inches each 100 feet, and just through the upper edge of the springy area. Short laterals may need to be added a year or two later to complete the drainage.

Laterals for Peat and Muck Soils. — Raw peat is subjected to considerable shrinkage upon drainage, and 4 feet is regarded as a minimum depth for laterals. Deep, raw, peat soils will

be greatly benefited by laterals placed 500 or even 1000 feet apart. Where considerable silt is present, so that the soil is a rather dense muck, more thorough drainage is required, and the drains should then be only 3 or 4 feet deep.

Peaty Silt Loam or Tide-Land. — Near Astoria, at the Astoria Branch Experiment Station, an experimental drainage system has been installed on diked tide-land, and so arranged that guarded laterals are 50, 75 and 100 feet apart, and from 3 to 5 feet deep. The depth is greater where the laterals are 100 feet apart. Outflow, water-table, and yield data for the first season indicate that in tide-lands, where a sufficient depth of outlet can be secured, field laterals may be placed 4 feet deep and 75 or 80 feet apart.

Shallow peat that is underlain with black clay loam, or blue silty clay loam, is less attractive and less susceptible to drainage improvement. Peat, with some organic material, and especially with some sand deposited by water action, is readily drained and is apt to supply more evenly balanced plant-food. In some of the "beaver-dam" areas in the Willamette Valley, where the water-table disappears naturally late in the season, permitting thorough maturing of onions and other crops, the growers prefer to have laterals only 30 or 36 inches deep, in order that the crop may sub-irrigate early in the season. Raw peat may not "sub" over 18 inches, while silty peat may sub-irrigate 30 inches to 36 inches above the water-table. Where sub-irrigation is desired it would probably be better to have the laterals at least 4 feet deep, and to provide check-gates in the outlet drains, to delay the removal of the water-table beyond the reach of crop roots until later in the growing season. Grass will flourish with a water-table 2 feet from the surface, while for grain a depth of 3 or 4 feet, and for clover and other legumes a depth of 4 or 5 feet would be better. A large amount of valuable marsh land awaits reclamation on the Pacific and Atlantic coasts, and the subject warrants special study.

Laterals for Irrigated or Alkali Lands. — In draining irrigated lands, the drains must be placed at a great depth. Fre-

quently a drain intended to intercept seepage is located in some deep, porous stratum where the water can be collected before it injures the field below. A common depth in draining irrigated land is 6 or 8 feet. Silty loam is the prevailing type among irrigated lands in this state that appear capable of reclamation at present. There are areas of heavy loam or clay loam, "grease-wood land," in places in Eastern Oregon, which are so located that they can be improved by surface drainage and flushing off the alkali salts through open ditches. At high altitudes where outlets are not readily secured, the reclamation of such tracts by underdrainage does not appear feasible at present.

For thorough drainage of alkali lands, where protecting drains cannot be employed, 5 or 6-inch laterals placed 440 to 680 feet apart, making two or three laterals to a "forty," should provide fairly thorough drainage if a porous layer can be encountered at a depth of 6 or 8 feet below the soil surface. The efficiency of such drains will depend upon the prevalence of water and the amount of irrigation employed for the particular texture of soil to be dealt with. A study of subsoil conditions will reveal the presence of porous layers through which water is passing and in which drains can be placed to collect it. These layers must be so deep that drains placed in them will overcome the capillary action between the water-table and the surface.

Studies of the relation of the water-table to the concentration of alkali on the surface have been made in several valleys in Eastern Oregon, by means of systems of wells whose elevations have been determined and from which regular observations of the water-stage have been made. Studies on the Malheur bottom revealed the fact that a sandy streak may be encountered at from 5 to 9 feet below the surface, while a quite porous, gravelly layer can usually be found at a depth of 8 to 12 feet. The maximum accumulation of alkali in this heavy loam soil occurs where the water-table is about 3½ feet below the surface. Water comes rapidly into the post-holes from these porous layers in the subsoil; and from these studies

we are convinced that the drainage of these lands is feasible, considering the high amount of plant-food the soils contain, and the favorable climate in which they are located. Similar studies have been made on alkali lands near Haines and in other places.

Drainage of irrigated land in the Klamath Basin is being secured most readily by cutoff drains across the slope or below the canals. There is a layer of water-bearing sand on the chalk rock at a mean depth of about 5 feet, the depth at which drains work best. A 14-inch Austin ditcher is used for the excavation by the United States Reclamation Service.

Valuable areas of alkali land located at moderate elevations, as in the Umatilla, Crooked River, and Walla Walla Valleys, offer very attractive fields for reclamation. At high elevations where thorough underdrainage is not justifiable under present economic conditions, there are many places where winter or late fall irrigation could be practiced, and the alkali flushed off into available outlet channels.

TABLE VII. — AVERAGE PRACTICE FOR LOCATION OF LATERALS

Soil	Depth	Distance Between Laterals
Clay	33 in.–36 in.	2–3 rods
Clay Loam	36 in.	3–4 rods
Silt Loam	36 in.–42 in.	5 rods
Loam	36 in.–48 in.	6 rods
Sandy Loam	36 in.–48 in.	6–12 rods
Sand	42 in.–48 in.	12–20 rods
Peat	48 in.–60 in.	5–12 rods
Irrigated Land	60 in.–100 in.	10–40 rods

In draining irrigated land, relief wells may be used to bring up water from deep water-bearing gravel to a depth at which it can be reached by drains. Precautions must sometimes be taken in water-logged soil to avoid caving in during construction; and the back filling may need to be tamped, so that irrigation water may leach out the whole soil instead of per-

colating directly into the drains. Some manholes should be provided to afford an opportunity for observation and for cleaning out roots and silt from the drains.

QUESTIONS

1. Name the factors which determine the proper depth for laterals and distance between them.
2. Explain the relation between depth for drains and distance between them.
3. Explain relations between kind of crop and proper depth for drains.
4. What is the effect of different soil types on proper depth?
5. How do changes in soil strata affect depth for tile?
6. What is the effect of amount and distribution of rain upon drains?
7. Explain the effect of soil texture on distance between drains.
8. For what distance will a tile line affect the water-table in sand? In clay? Within a reasonable time after rains?
9. What materials can be used for bedding over tile lines?
10. Explain the relation of distance between drains to rate of drainage.
11. What effect would deeper drainage have on duration of outflow?
12. What would be a reasonable depth and distance for laterals in loam soil? In clay?
13. What system of drainage would be suitable for flat, heavy clay adjacent to upland?
14. What would be a suitable distance between laterals, to provide drainage for ordinary field crops in tide-land?
15. What arid soil characteristics affect drainage in arid sections?

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CHAPTER VIII

MEASUREMENT OF DRAINAGE-WATER

MEASUREMENT of drainage-water may be desirable in order to determine the size of tile or channel needed, to learn the capacity of a given sized tile, or to learn the amount of outflow from a given tile system.

Units and Equivalents. — Water is most dense at 39.2° F. and weighs 64.425 pounds to the cubic foot at that temperature. A cubic foot contains 7.48 gallons. *The inch-foot,* which is 1 inch deep over 1 square foot, weighs 5.2 pounds. *The acre-inch* is equivalent to 1 inch deep over 1 acre, or $\frac{1}{12}$ of 43,560 cubic feet, and equals 3630 cubic feet, or is equal to 1 inch rainfall over 1 acre. The flow from large tiles or the discharge from an open ditch is best expressed in cubic feet each second, or *second-feet.* This refers to the number of cubic feet passing a given point each second of time. An outlet-box 1 foot deep and 1 foot wide filled with water moving at a velocity of 1 foot per second would discharge 1 cubic foot each second. A cubic foot to the second is equivalent to 60 cubic feet a minute, or 3600 cubic feet an hour, being approximately 1 acre-inch an hour, or one acre-foot in 12 hours. The second-foot is approximately $7\frac{1}{2}$ gallons to the second, or 450 gallons a minute.

The quantity of water flowing is always equal to the cross-sectional area of a stream times the velocity, that is, quantity equals area times velocity. Thus, $Q = A V$.

Where A is the area in square feet and V is the velocity in feet to the second, quantity, or Q, will be obtained in cubic feet per second. The area of a stream can always be determined by cross-sectioning. This may be done by holding a tape across the surface of the stream on the smooth part where the channel is clear, and measuring the depth at regular in

tervals across the stream. This divides the whole area into small sections of trapezoidal or triangular shape. The area of each section can then be determined and totaled, to secure the cross-section of area. Taking measurements in decimals of a foot will facilitate calculations for securing the cross-sectional area in square feet. The velocity of a stream can be obtained roughly by chips, more accurately by formulas involving cross-section and slope, or still more accurately by a current-meter.

Measurement by Chips. — To be measured by chips, a stream should first be cross-sectioned as above described, to determine the cross-sectional area in square feet. A straight, smooth section of channel should be measured off or paced for a definite distance along the stream. A chip should be floated at the upper end of this course and the time it requires to run the measured course of the stream should be noted. Chips should be run at frequent intervals across the stream so that the average velocity is secured. If the average time required for the chip to travel 50 feet, should be 25 seconds, the stream's mean velocity would be 2 feet per second. This velocity in feet per second, multiplied by the area in square feet, will give the discharge in cubic feet per second. In small streams the surface velocity should be multiplied by 0.8 to give more nearly the mean velocity. Instead of this, the mean velocity for different sections of the stream may be secured directly by the use of weighed chips or partly submerged bottles.

Meter Measurements. — The current-meter is an instrument designed to determine the velocity of a stream, and is rated by moving it through still water at different velocities. A table is then prepared from which the velocity in cubic feet per second can be determined. A current-meter is usually provided with a telephone receiver or electric connection, so that the number of revolutions can be determined by the observer for definite intervals of time. It is customary to arrange the instrument so that a tap is heard or registered for each 1, 5 or 10 revolutions, according to velocity of the stream and a table which gives the velocity for the observed number

of seconds to each revolution. Observations are usually obtained for 5 or 10 seconds at each of several points across the stream. The mean velocity in any vertical line will usually be obtained by holding the meter at $\frac{6}{10}$ the distance from the bottom of the stream to the surface. It may also be obtained by taking the average velocities at $\frac{2}{10}$ and $\frac{8}{10}$ the depth. Instead of this the meter can be slowly raised and lowered during the observation to obtain the mean velocity. The table provided with the meter will give the velocity in feet per second for any interval of time required to make 100 revolutions. This mean velocity in feet per second, multiplied by the area, will give the discharge in second-feet.

Formulas for Velocity and Discharge. — Formulas have been developed for determining the flow of water (*a*) in open streams (*b*) through pipes and tile lines, and (*c*) through standard measuring weirs.

Gravity is the cause of flow of water, whether running down an incline or falling vertically. The formulas for water velocity and measurement of water are based on a formula used to express the theoretical velocity due to gravity. In the case of freely falling bodies

$$V = C\sqrt{2gh}$$

In which

V = velocity in feet per second.
g = accelerating force due to gravity, or 32.2.
h = space or head through which the body falls.
C = constant usually about $\frac{6}{10}$.

This formula applies to orifices only.

A. Formula for Open Channel. — The formula usually applied to the pipe or open channel is $V = C\sqrt{rs}$, the Chezy formula with the Kutter coefficient, often called the Kutter formula.

$$C = \frac{41.65 + \frac{0.00281}{s} + \frac{1.811}{n}}{1 + \left(41.65 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{r}}}$$

In this formula, n = constant depending on the roughness of the channel

s = fall in feet divided by the length in feet

r = hydraulic mean depth = $\frac{A}{P}$ where A is area of waterway and P is the wetted perimeter of the channel cross-section.

This formula, although too formidable for ready longhand calculation, is quickly solved by the use of diagrams; or the following table together with Table VIIB of the Appendix, taken from Russell's "Text-Book on Hydraulics," will give C, after which the velocity and discharge can be more easily computed.

TABLE VIIa

Coefficient (C) in Kutter's Formula

Slope s	n	Hydraulic Radius r in Feet														
		0.2	0.3	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	4.0	6.0	8.0	10.0	15.0
.00005	.010	87	98	109	123	133	140	154	164	172	177	187	199	207	213	220
	.012	68	78	88	98	107	113	126	135	142	148	157	168	176	182	189
	.015	52	58	66	76	83	89	99	107	113	118	126	138	145	150	159
	.017	43	50	57	65	72	77	86	93	98	103	112	122	129	134	142
	.020	35	41	45	53	59	64	72	80	84	88	95	105	111	116	125
	.025	26	30	35	41	45	49	57	62	66	70	78	85	92	96	104
	.030	22	25	28	33	37	40	47	51	55	58	65	74	78	83	90
.0001	.010	98	108	118	131	140	147	158	167	173	178	186	196	202	206	212
	.012	76	86	95	105	113	119	130	138	144	148	155	165	170	174	180
	.015	57	64	72	81	88	93	103	109	114	118	125	134	140	143	150
	.017	48	55	62	70	75	80	88	95	99	104	111	118	125	128	135
	.020	38	45	50	57	63	67	75	81	85	88	95	102	107	111	118
	.025	28	34	38	43	48	51	59	64	67	70	77	84	89	93	98
	.030	23	27	30	35	39	42	48	52	55	59	64	72	75	80	85
.0002	.010	105	115	125	137	145	150	162	169	174	178	185	193	198	202	206
	.012	83	92	100	110	117	123	133	139	144	148	154	162	167	170	175
	.015	61	69	76	84	91	96	105	110	114	118	124	132	137	140	145
	.017	52	59	65	73	78	83	90	97	100	104	110	117	122	125	130
	.020	42	48	53	60	65	68	76	82	85	88	94	100	105	108	113
	.025	30	35	40	45	50	54	60	65	68	70	76	83	86	90	95
	.030	25	28	32	37	40	43	49	53	56	59	63	69	74	77	82
.0004	.010	110	121	128	140	148	153	164	171	174	178	184	192	197	198	203
	.012	87	95	103	113	120	125	134	141	145	149	153	161	165	168	172
	.015	64	73	78	87	93	98	106	112	115	118	123	130	134	137	142
	.017	54	62	68	75	80	84	92	98	101	104	110	116	120	123	128
	.020	43	50	55	61	67	70	77	83	86	88	94	99	104	106	110
	.025	32	37	42	47	51	55	60	65	68	70	75	82	85	88	92
	.030	26	30	33	38	41	44	50	54	57	59	63	68	73	75	80
.001	.010	113	124	132	143	150	155	165	172	175	178	184	190	195	197	201
	.012	88	97	105	115	121	127	135	142	145	149	154	160	164	167	171
	.015	66	75	80	88	94	98	107	112	116	119	123	130	133	135	141
	.017	55	63	68	76	81	85	92	98	102	105	110	115	119	122	127
	.020	45	51	56	62	68	71	78	84	87	89	93	98	103	105	109
	.025	33	38	43	48	52	55	61	65	68	70	75	81	84	87	91
	.030	27	30	34	38	42	45	50	54	57	59	63	68	72	74	78
.01	.010	114	125	133	143	151	156	165	172	175	178	184	190	194	196	200
	.012	89	99	106	116	122	128	136	142	145	148	154	159	163	166	170
	.015	67	76	81	89	95	99	107	113	116	119	123	129	133	135	140
	.017	56	64	69	77	82	86	93	99	103	105	109	115	118	121	126
	.020	46	52	57	63	68	72	78	84	87	89	93	98	102	105	108
	.025	34	39	44	49	52	56	62	65	68	70	75	80	83	86	90
	.030	27	31	35	39	43	45	51	55	58	59	63	67	71	73	77

For use with this table, the following values of n, the roughness factor for various materials are given:

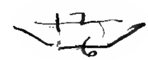
Very smooth glazed or planed wood surfaces	0.009
Smooth clean cement	0.010
Rough lumber and new brickwork	0.012
Smooth stone, iron and ordinary brick	0.013
Drain-tile as ordinary laid	0.015
Rough ashlar and good rubble masonry	0.017
Gravel	0.020
Ordinary earth (good condition)	0.025
Earth channel with stones and weeds	0.030
Earth or gravel in bad condition and stream with drift, etc.	0.035

Example:

Compute the flow from an open channel in gravel soil, when the bottom width is 6 feet, depth is 3 feet; side slopes are 1 to 1 or 45° and fall is 5.3 feet per mile.

$$s = \frac{5.3}{5280} = .001$$

$$n \text{ for gravel} = 0.020$$



$$r = \frac{A}{p}$$

where

$$A = \frac{6 + 12}{2} \times 3 = 27 \text{ sq. ft.}$$

and

$$p = 6 + 2 \times 3\sqrt{2} = 14.5$$

whence

$$r = \frac{27}{14.5} = 1.89 \text{ (nearly 2)}$$

$$V = C\sqrt{rs}.$$

entering table with above values of n, r, and s we find C lies between 78 and 84 or about 83

whence

$$\begin{aligned} V &= 83\sqrt{1.89 \times 0.001} \\ &\ 83\sqrt{0.001890} = 83 \times 0.043 \\ &= 3.57 \text{ feet per second,} \end{aligned}$$

and the discharge,

$$Q = 3.57 \times 27 = 96 \text{ cubic feet per second}$$

The Chezy formula, much used by engineers in hydraulic calculations, is as follows:

$$V = C\sqrt{rs}$$

In which

V = velocity in feet per second.

C = A variable coefficient found by reference to curves or tables.

r = hydraulic mean depth, or area of waterway divided by the wet perimeter or length of bounding line of cross-section of channel under water.

s = Size of slope, or fall in feet divided by the length in feet.

A simplified form of this formula has been used by Elliott, with good results, for open ditches, using 8 of the depth of channel for computing flow, as follows:

$$V = \sqrt{\frac{a}{p} \times 1\tfrac{1}{2}\, h}$$

and

$$Q = AV$$

Where

V = velocity in feet per second.

A = area of waterway in square feet.

p = wet perimeter.

h = fall in feet per mile.

Q = discharge in cubic feet per second.

Water flowing down an incline encounters resistances of various kinds which tend to make the velocity moderate and uniform. Formulas have been developed by painstaking experiments to represent these factors in streams and pipes.

B. Tile-Size Formulas. — There are a number of formulas in use for computing flow of water in pipes, or determining the size of tiles needed for given depths of removal in a given time. Poncelet's formula has been used, but has been largely super-

ceded by the Chezy formula mentioned above, sometimes called Kutter's formula, $V = C\sqrt{rs}$, in which $r = \frac{D}{4}$ for pipe flowing full or half full. C varies with n, r and s, and must be determined. The following example will illustrate the use of this formula for tile.

Example: Sr

Compute the flow in an 8-inch cement drain-tile, flowing half full, when laid on a slope of $\frac{3}{4}$ inches to the rod.

$$r = \frac{A \text{ in feet}}{p \text{ in feet}} = \frac{\left(\frac{8}{12}\right)^2 \times 3.1416 \times \frac{1}{4} \times \frac{1}{2}}{3.1416 \times \frac{8}{12} \times \frac{1}{2}} = 0.166 \text{ feet} = 0.2 \text{ (nearly)}$$

$$s = \left(\tfrac{3}{4} \times \tfrac{1}{12}\right) \div 16\tfrac{1}{2} = \frac{3}{48 \times 16\frac{1}{2}} = 0.0049 = 0.005 \text{ (nearly)}$$

16

$n = 0.015$

entering the table with

$n = 0.015$, $r = 0.020$ and $s = 0.005$

we find the slope lies between 0.001 and 0.010; hence we must get the C for each slope and take average using slope $= 0.001$, $r = 0.2$ and $n = 0.015$ we find $C = 0.66$; likewise for the steeper slope it is 0.67

$$\begin{aligned} \text{therefore} \quad V &= 66\tfrac{1}{2}\sqrt{rs} = 66\tfrac{1}{2}\sqrt{0.16 \times 0.005} \\ &= 66\tfrac{1}{2}\sqrt{0.00087} \\ &= 66\tfrac{1}{2} \times 0.029 \\ &= 1.92 \text{ feet per second} \end{aligned}$$

and the discharge in cubic feet per second, designated by Q, is 1.96. $Q = AV = 3.1416 \times \left(\frac{8}{12}\right)^2 \times \frac{1}{4} \times 1.92 = 0.67$ cubic feet per second.

0.60

Many diagrams have been proposed for the simplification of the solution of Kutter's formula; but the most convenient one for the drainage student is probably the following, furnished

by the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Department of Agriculture.

These diagrams can be prepared for a channel of any shape with any depth of flow, at any slope, and for any degree of roughness, "*n*."

The following diagram is prepared for tile-drains for which the degree of roughness, "*n*," is 0.015, slopes from 0.02 to 5 feet per 100 feet and diameters of 4 inches to 48 inches. At the right of the diagram is shown the number of acres drained at different rates of runoff and discharges in cubic feet per second equal to those horizontally opposite on the scale at the left-hand side.

For other values of n other diagrams will be needed.

These diagrams are plotted to a logarithmic scale, because such a scale gives straight lines instead of curves, which is a decided advantage in using the diagrams.

Any engineer using these scales should plot them to larger scale on mounted paper, to eliminate errors from shrinkage and expansion with change in atmospheric conditions.

The following examples illustrate the use of the diagram.

Example 1. Find the discharge from a 10-inch drain on a 0.5 per cent grade ($s = 0.005$) $n - 0.015$.

Solution:

On the bottom scale find 0.5; follow the vertical line through this figure to its intersection with the diagonal line marked 10 " tile." From this intersection, follow horizontally to the left and we find discharge = 1.2 cubic feet per second. Following horizontally to the right we find this tile line will drain approximately 115 acres when the runoff is $\frac{1}{4}$ inch deep, in 24 hours, or 75 acres when the runoff is $\frac{3}{8}$ inch in 24 hours.

Example 2

What size tile, laid at 0.20 per cent grade, will drain 200 acres when the runoff is $\frac{1}{2}$ inch in 24 hours?

Solution:

Follow up the vertical line representing a grade of 0.20 per cent till this intersects the horizontal line from 200 acres in the $\frac{1}{2}$-inch runoff column at the right. This intersection comes

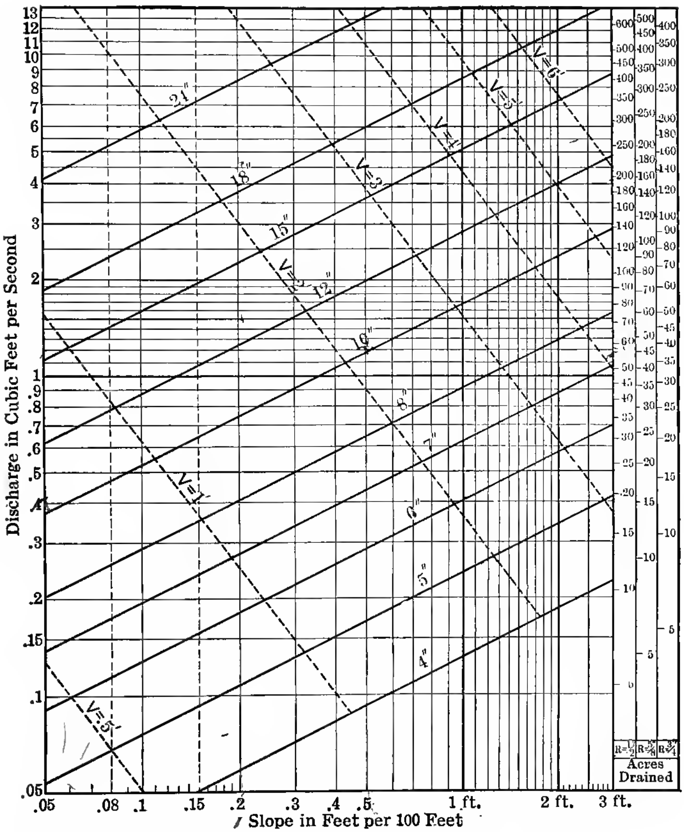


FIG. 21. Diagram showing discharge and tile size for different slopes based on Kutter's formula. (Courtesy Division of Agricultural Engineering, Bureau of Public Roads, U. S. Department of Agriculture.)

between an 18-inch and a 20-inch tile. We would therefore use the larger size to be on the safe side.

The number of acres served by tiles of given or assumed diameter is found by dividing the discharge by a constant representing the number of cubic feet per second needed to be removed in order to relieve one acre of a given depth in twenty-four hours; *i.e.*, the cubic feet per second per acre corresponding to the given drainage coefficient.

The Drainage Coefficient is the depth in inches to be removed from the drainage area in twenty-four hours. The quantity in cubic feet a second to the acre, for the drainage coefficients commonly used, is as follows:

TABLE VIII

Drainage Coefficient. Depth of discharge in inches per acre per 24 hours	Tile constant Second-feet
$\frac{1}{8}$	.0052
$\frac{1}{4}$	0.0105
$\frac{1}{3}$	0.0140
$\frac{1}{2}$	0.0210
$\frac{3}{4}$	0.0315
1	0.0420

The coefficient multiplied by the number of acres will give the total quantity to be handled in cubic feet per second. The quantity determined by the Poncelet formula to be the amount a given tile is capable of handling, divided by the constant to be used, will show the number of acres a tile is capable of serving. The number of acres from which $\frac{1}{4}$ inch in depth of water in twenty-four hours will be removed by a system of drainage which has a main 1000 feet long, for the different sizes and grades worked out by the above formula, is given in the following table:

TABLE IX.—NUMBER OF ACRES DRAINED OF $\frac{1}{4}$ INCH OF WATER IN 24 HOURS

Grade per 100 Feet in Decimals of a Foot (with Approximate Equivalent in Inches)

Diameter of Tile in Inches	0.05 ($\frac{5}{8}$ inch)	0.10 ($1\frac{3}{16}$ inch)	0.20 ($2\frac{3}{8}$ inch)	0.30 ($3\frac{5}{8}$ inch)	0.50 (6 inch)
		Acres of Land Drained			
5	17.7	19.8	23.5	26.7	32.0
6	28.0	31.2	37.0	42.0	50.5
7	41.1	45.9	54.3	61.6	74.0
8	57.3	64.0	75.6	85.8	103.3
9	76.5	85.6	101.4	114.9	138.1
10	99.5	111.2	131.6	149.3	179.2
12	156.1	174.8	206.8	234.5	281.8
14	228.7	256.1	302.5	343.5	412.9
16	317.8	355.4	420.6	477.4	573.7
18	424.9	475.7	562.2	638.1	767.4

Weirs and Weir Measurements.—The most accurate, practical, and economical method for the yet devised measurement of moderate amounts of flowing water is the weir measurement. The weir is a thin notch of definite shape over which the water is caused to flow. The amount of flow depends on the length of crest or bottom of the notch and depth of water flowing over the crest. There are several forms of weirs; but conditions governing their location are the same, the only difference being in the shape of notch and in the formula used in computing the discharge. The trapezoidal weir is about the most convenient and is coming to be most generally used in the West. This weir, as its name implies, is trapezoidal in shape, with a straight bottom and with sides having a run of 1 to 4 of rise. A 1-foot trapezoidal weir has a notch-width of 1 foot and is 16 inches wide 8 inches above the crest or base of the notch. The crest and sides should be sharp on the upstream side and the water should have a free spillway. When all conditions are met carefully, this weir will measure water with error of less than 1 per cent.

Setting the Weir. — In order to prevent leakage around or under the weir, and to add stability, the weir is often provided with a weir-box, which must be large enough in proportion to the notch to eliminate friction and excess velocity of approach. This requires a box or ditch, with a cross-section of at least 7 times the area of the notch. The distance from the crest to the sides should be twice as great as any possible depth of water flowing over the crest; and the distance from crest to bottom should be 3 times the depth of water that may flow over. The weir-plate must set plumb and the crest level, and the length of the crest should be at least 3 times the depth of water flowing over it. With the proportions given, there will be no appreciable velocity of approach, not over 6 inches to the second. The peg for measuring depth should be located at least 3 feet upstream from crest, to avoid draw down, and should read zero, or set flush with the water surface when the water is on a level with the crest and just ready to break over. It is not necessary here to go into details regarding principles and mathematics involved in the formula for the weir. Engineers have experimented for years and found that, under like conditions, the same depth always produces the same discharge over a given sized weir. The amount of water passing through each second depends on the area and the gravity head, also the side slope, location of weir, contraction, and cohesion. All of these are represented in the formula which has been evolved as follows:

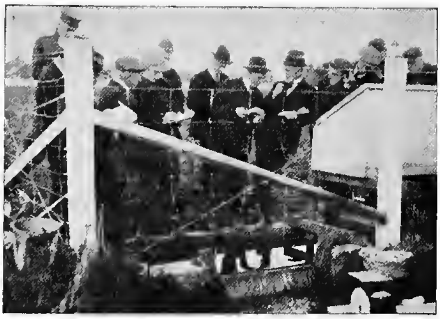


FIG. 22. Weir and drainage system outlet.

Quantity equals 3.367 × the length in feet × the height in feet raised to the 3/2 power. That is, the height in feet or decimal of a foot is cubed; the square root is obtained, which

is then multiplied by the length in feet and then by the constant 3.367.

In order to save calculations, we usually employ a weir table which gives the discharge for different depths and various lengths, the results having been computed from the above formula.

Method of Using Weir Table. — The head of water flowing over the weir should not be measured until the water has run a little while and the flow becomes steady. It can then be measured by placing upon the peg an ordinary rule graduated in inches. In reading the rule the eye should be held near the level of the water.

How to Use the Tables. — Suppose we have a 2-foot weir, and measure the water flowing over it with a common rule and find the depth above the peg to be $4\frac{1}{4}$ inches. Turning to Table X in the first column, under the heading "Depth over Crest," we slip down the column to $4\frac{1}{4}$ inches, then horizontally across to the fourth column under 2-foot weir, and find 1.418 second-feet; while in the fifth column we find the number of miner's inches, which in this case is 56.7 miner's inches.

Using figures corresponding to the different sizes of weirs and depths of flow encountered, the depth an acre removed in a given time can be determined.

A Few Precautions. — Avoid setting a weir close to or just below a curve in a ditch, as this causes water to go to one side.

Do not set a weir close to or just below a headgate where there is a high velocity.

Do not allow water below the crest to back up even with the crest, or confine air underneath, for this lessens the discharge.

Always set the weir perpendicular to the current.

Never allow the pool above the weir to fill up with sediment.

For the measurement of silt-laden water, or where the necessary fall cannot be obtained, a rating flume or current-meter will be found more desirable than a weir.

TABLE X. — DISCHARGE OF TRAPEZOIDAL WEIRS IN SECOND-FEET, COMPUTED FROM THE FORMULA,

$$Q = 3.367\ L.\ H^{3/2}.$$

Depth of Water on Crest (inches)	1-foot Weir Second-feet	2-foot Weir Second-feet	3-foot Weir Second-feet
¼	.010	.020	.030
½	.029	.058	.087
¾	.053	.106	.159
1	.081	.162	.243
1¼	.113	.226	.339
1½	.149	.298	.447
1¾	.188	.376	.564
2	.299	.458	.687
2¼	.273	.546	.819
2½	.320	.640	.960
2¾	.369	.738	1.107
3	.421	.842	1.263
3¼	.474	.948	1.422
3½	.530	1.060	1.590
3¾	.588	1.176	1.764
4	.648	1.296	1.944
4¼	.709	1.418	2.127
4½	.773	1.546	2.319
4¾	.839	1.678	2.517
5	.906	1.812	2.718
5¼	.974	1.948	2.922
5½	1.044	2.088	3.132

TABLE XI. — DISCHARGE OF TRAPEZOIDAL WEIR IN ACRE-FEET PER HOUR

Depth of Water on Crest in inches	Acre-Feet in one Hour			Depth of Water in inches	Acre-Feet in one Hour		
	1-foot Weir	2-foot Weir	3-foot Weir		1-foot Weir	2-foot Weir	3-foot Weir
¼	.0008	.0016	.0025	3¼	.0391	.0784	.1176
½	.0023	.0047	.0071	3½	.0438	.0876	.1315
¾	.0043	.0087	.0131	3¾	.0486	.0971	.1458
1	.0067	.0137	.0201	4	.0535	.1067	.1600
1¼	.0093	.0187	.0280	4¼	.0586	.1172	.1758
1½	.0123	.0246	.0369	4½	.0639	.1278	.1917
1¾	.0155	.0309	.0464	4¾	.0693	.1385	.2079
2	.0189	.0378	.0567	5	.0748	.1497	.2231
2¼	.0225	.0452	.0676	5¼	.0803	.1608	.2414
2½	.0263	.0529	.0792	5½	.0863	.1726	.2589
2¾	.0305	.0610	.0915	5¾	.0922	.1864	.2768
3	.0348	.0696	.1043	6	.0984	.1967	.2951

QUESTIONS

1. What are the purposes for which drainage water is measured?
2. Define the inch-foot, the acre-inch, the second-foot.
3. How should the cross-sectional area of a stream be determined?
4. What different methods are used for determining velocity of a stream?
5. Describe the procedure in determining velocity by means of floats.
6. What is a current-meter and how is it used?
7. What causes flow of water?
8. Define hydraulic mean depth, wetted perimeter, drainage coefficient, weir.
9. What things tend to retard flow in pipes, in tiles, in open channels?
10. Using a drainage coefficient of $\frac{1}{4}$ inch, calculate the number of acres for which an 8-inch tile 2000 feet long, laid on a grade of 0.2 feet per 100, will furnish an outlet.
11. What corrections are applied in calculations for open soil? In case of steep sub-mains?
12. How would a 1-foot trapezoidal weir with 4-inch depth be laid out and cut, if cut out of a 12-inch plank?
13. What precautions are necessary in setting a weir?
14. Calculate the discharge from a 2-foot weir with a head of 0.25 feet.

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CHAPTER IX

SIZE AND GRADE FOR TILES

Size. — In order to secure fairly complete drainage at the lowest possible cost, the size of tiles to use for a main drain should be determined after all data regarding the available fall and the land and water conditions are at hand. Size of tiles refers to inside diameter expressed in inches. The area of cross-section of a tile increases as the square of the diameter. The effect of friction and eddies is not so great in large tiles, so that an 8-inch tile has more than 4 times the capacity of a 4-inch tile with the same amount of fall.

Tile-size also depends on (1) slope of drain, (2) area to be drained, (3) friction and eddies, (4) drainage coefficient. Drainage coefficient has been defined, and is affected by the items given here as affecting size of tile. It is, of course, affected by many other things, some of which are discussed in the chapters on soils and soil-water. Some of the factors to be kept in mind are amount, intensity, and seasonal distribution of rainfall, or amount of irrigation, also evaporation, transpiration and prevalence of underground water. It is important to consider the rate of removal of excess water that is necessary to avoid injury to the crops to be grown, the fineness and storage capacity of the soil, and the extent and topography of the watershed and area to be drained. Where surface inlets are used, the tile-size will need to be greatly increased.

There are times when the soil is so dry that 3 or 4 inches of rain will scarcely start the water flowing in tiling. At other times, when the soil is nearly saturated, it will be necessary to remove the larger part of the rainfall within forty-eight hours. At times, water cannot pass through the soil fast enough, even though the tiling is amply large, so that the surface runs or surface inlets are needed. Where these are used,

the tile capacity should be greatly increased. On November 5, 1910, following a very dry season, rains began at the Oregon Experiment Station, and continued until November 10, amounting to 4.94 inches. This rain was just sufficient to start tile-drains on the Experiment Station farm and cause light runoff.

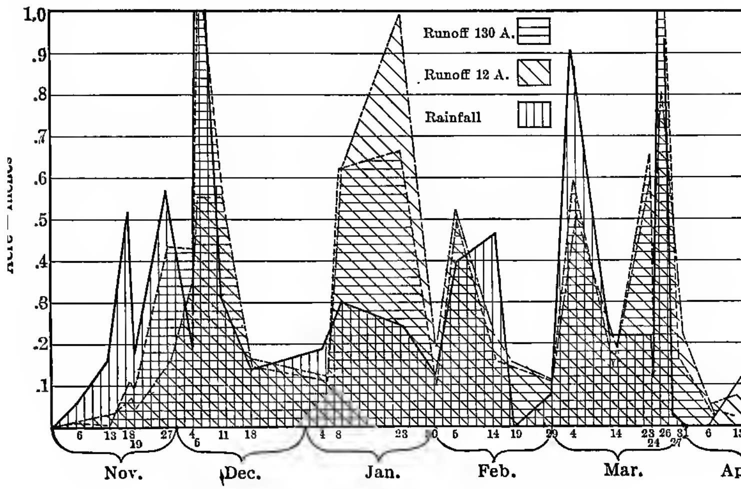

FIG. 23. Hydrograph of rainfall and runoff.

The average depth of these drains is about 34 inches, and the water-retaining capacity of this land under field conditions is, therefore, a little less than 2 inches rainfall for each acre-foot of soil. The size of the tiling must be sufficient to deal with the heaviest rainfall, excepting only unusually heavy storms.

The main tiles collect water from the laterals; yet it is unnecessary for the main drain to have a capacity equal to the combined capacity of laterals; for laterals rarely flow more than half full.

Yearly precipitation at the Oregon Experiment Station is about 42 inches; the maximum monthly precipitation rarely exceeds 12 inches. Although as much as 2 inches in twenty-four or over 3 inches in forty-eight hours may occur once or twice each winter, there are only eight or twelve days each

year when as much as 1 inch of precipitation occurs in twenty-four hours.

Excess water in more arid sections comes less directly from precipitation, which may total 10 to 20 inches. In the heart of the corn belt the yearly precipitation ranges from 30 to 36 inches.

Runoff depends on soil, topography, vegetation, weather conditions, and other factors discussed in another section. A surface run will be helpful to supplement tiling, where run-off aids in removal of excess water.

The evaporation from a water surface at Corvallis, from April to October, averages about 24 inches. The remainder of the year the evaporation is very low. In most humid sections, annual evaporation from a water surface exceeds rainfall.

The outflow from underdrains has been studied by the Office of Drainage Investigations, U. S. Department of Agriculture. This office determined the capacity of a large number of tile systems in Illinois and Iowa, where the capacity was regarded as satisfactory by the landowners. The annual rainfall in those districts was 33 to 35 inches, and was fairly evenly distributed. From these studies, it was concluded that tiling having capacity to remove $\frac{1}{4}$ inch to the acre in twenty-four hours from the area tiled would provide satisfactory drainage under those conditions.

Recent elaborate investigations, taking account of modern tendencies towards thorough drainage, have shown that $\frac{1}{4}$ inch is not enough in Iowa[1], and should be increased to $\frac{5}{16}$ or $\frac{3}{8}$ inch and fixed according to local conditions. This conclusion is based on eight years observations, including systematic rainfall, water-table and outflow measurements from six tile systems serving areas of from 10.8 to 443 acres.

Outflow from 10 acres in Central Park, New York City, was measured for several months under direction of Col. Waring, who installed drainage for the tract. A portion of the data there secured is presented in the following table:

[1] Schlick, W. J. Engineering Experiment Sta. Bul. No. 52, Ames, Iowa, 1918.

TABLE XII. — OUTFLOW FROM 10-ACRE TILE SYSTEM, CENTRAL PARK, NEW YORK CITY

Period	Precipitation Total for Period	Mean Daily	Maximum Total	Outflow, Total for Period	Acre-Inches an acre in 24 hrs.	
					Mean Daily	Maximum Observed
July 13–16	2.20	.73	2.20	.28	.09	.18
16–23	1.23	.17	1.23	.66	.07	.28
23–25	.06	.03	.06	.04	.02	.02
Aug. 3–13	2.40	.24	1.61	.64	.06	.30
13–15	.71	.35	.71	.07	.03	.04
24–27	.26	.08	.20	.60	.20	.28
Sept. 11–20	1.83	.20	1.01	.48	.05	.19
20–26	2.08	.35	1.49	.80	.13	.28
Nov. 22–24	1.07	.53	1.07	.38	.19	.19
Total	11.84	...	...	3.95	...	...

This table indicates that tiling with capacity to handle $\frac{1}{4}$ to $\frac{1}{3}$ inch an acre in twenty-four hours would be satisfactory under conditions existing in New York.

Measurements of the outflow from a tile system draining 3 acres at Uniontown, Alabama, indicate that from 23 to 68 per cent of heavy rainfall was discharged within a few days after rain.

Experiments Relating to Size of Tiling. — Measurement of discharge from several drainage systems in the vicinity of Corvallis, designed to handle $\frac{1}{2}$-inch rainfall or more for each acre in twenty-four hours, have been made for the past three years. The outflow has frequently exceeded the $\frac{1}{2}$-inch coefficient. One tile system with no surface inlets, draining 30 acres of "white land" and having $\frac{1}{2}$-inch capacity, was charged at least three times the past winter for one or more days. Fairly regular measurements of the discharge from outlets of four drainage systems were made during the past season. The watershed areas were determined from surveys made by Professor Teeter.

Except for the 130-acre area, measurements were made by

collecting water and measuring or weighing it. A weir with automatic register was installed to measure the underdrainage, and flood-water was rated with a current meter. Table XIII gives the greater part of the data obtained.

The 12-acre area is that covered by the experimental drainage system, and has no surface inlets. The two smaller areas receive a little water through surface inlets. The area of 130 acres has surface inlets; but the tile system extends under less than half of it. The chief outlet for this large tract consists of 14-inch tiles, and there are also two 7-inch tiles leading to the outlet weir-box. Following the heaviest storm of the year, the runoff from the 130-acre area was 12 second-feet for a few hours, and at least 5 second-feet for twenty-four hours. On three or four occasions the total runoff reached 8 second-feet, or twice what the underdrains could carry.

The measurements of runoff and underdrainage indicate that in winter the percentage of runoff from small areas in this district is very high, at least 80 per cent of the rainfall. This is largely due to the wet atmospheric conditions, the heavy nature of the soil, and the limited amount of vegetation at this season of the year. The mean daily rainfall and mean runoff, in acre-inches an acre, is shown diagrammatically in the accompanying hydrograph.

The mean maximum discharge appears to be about $\frac{1}{2}$ inch for each acre in twenty-four hours, while the mean discharge is about .3 acre-inch for each acre in twenty-four hours.

Plant-food in Drainage-Water. — Samples of the first outflow in November, and of drainage from the experimental drain outlet in April were collected at the Oregon Experiment Station for analysis. The chemists found about 3 times as much nitrogen in the first outflow as in the second sample. Determinations by Mr. Carpenter of the Oregon Experiment Station follow:

Sample collected Nov. 24, 1915: 9.09 parts per million of nitrogen, NO_3.

Sample collected April 7, 1916: 3.60 parts per million of nitrate nitrogen, NO_3.

TABLE XIII. — RAINFALL AND OUTFLOW FROM DRAINAGE SYSTEMS

O. A. C. Experiment Station, 1915–1916

Period	Precipitation, (Inches)		Outflow, Main Drain College Farm 130 A		Outflow Exp. Drainage Field 12 A	
	Total for Period	Mean Daily	Second-feet	Acre-inches an Acre	Gal. per min.	Acre-inches an Acre
1915			In 24 hrs.		In 24 hrs.	
Oct. 30–Nov. 6	.50	.07	.01	.00	36	.02
6 13	1.15	.16	.01	.00	48	.03
13 18	2.62	.52	.08	.01	150	.08
18 19	.17	.17	.05	.01	135	.04
19 27	4.56	.57	2.36	.43	300	.16
27–Dec. 4	1.31	.19	2.36	.43	600	.32
Dec. 4 5	1.28	1.28	5.50	1.01	1000	.53
* 5 P. M. 6–8 hrs.	....	....	8.00	1.47	1000	.53
5 11	1.87	.31	3.05	.56	1000	.53
11 18	.89	.13	.84	.15	330	.18
1916						
18–Jan. 4	3.11	.18	.47	.09	1186	.10
Jan. 4 8	1.19	.30	3.46	.64	1200	.64
8 23	3.67	.25	3.57	.66	2000	1.06
23–6 hrs.	....	....	7.40	1.37	....	....
23 30	.87	.12	.53	.10	250	.13
30–Feb. 5	2.37	.39	2.55	.47	1000	.53
Feb. 5 14	4.16	.46	.90	.17	460	.21
14 19	0.00	.00	.77	.14	299	.16
19 29	.58	.06	.53	.10	203	.11
29–Mar. 4	3.53	.88	3.57	.66	1000	.53
Mar. 4 14	2.11	.21	.77	.14	284	.15
14 23	1.86	.21	3.57	.66	1122	.60
23 24	.12	.12	1.26	.23	561	.30
24 26 P. M.	3.17	1.57	12.00	2.21	1496	.80
26 27	.01	.01	4.50	.83	818	.44
27 31	.01	.00	.90	.17	141	.07
31–Apr. 6	0.00	.00	.23	.04	112	.06
Apr. 6 13	.75	.11	.11	.02	141	.07
13 21	.70	.87	.11	.02	112	.06
21 28	.46	.66	.08	.01	95	.05
28–May 1	0.00	.00	.08	.01	95	.05

* Includes surface runoff.

The total rainfall an acre received by drainage plots from November 30 to May 1 was 44.13 inches. The total acre-inches discharge an acre was approximately 35.30 or 78 per cent; and the total amount of nitrate nitrogen then removed was 50.62 pounds an acre, worth $2.28 if nitrogen is valued at $0.20 a pound. Without tiling, the heavy runoff must occur over the surface, carrying rich surface soil with it. Tile-water is clear, while runoff is very clouded. On the sand soil of the Umatilla Branch Experiment Station, Oregon, 150 to 125 pounds of nitrate is removed annually in the percolate from 6-foot lysimeter tanks. Lyon and Bizzell studied plant-foods removed in drainage, with different treatments, from lysimeters containing clay loam, and found higher nitrate loss in clean cultivated than in cropped soil.

Conclusions Regarding Drainage Coefficient. — Under conditions of 40 inches of rainfall, a coefficient of $\frac{1}{3}$ inch is indicated as suitable for large fields. For areas of 40 acres or less, where some surface inlets are to be used and little provision is to be made for surface runoff, capacity sufficient to remove $\frac{1}{2}$ inch for each acre in twenty-four hours is recommended.

For average conditions, as in the Central States, capacity to remove $\frac{5}{16}$ to $\frac{3}{8}$ inch an acre in twenty-four hours should be provided. Where the annual rainfall is not over 30 inches, $\frac{1}{4}$ inch per acre is a reasonable coefficient. These figures will vary with conditions.

Table ~~XIV~~ shows the number of acres from which $\frac{1}{4}$ inch of rainfall will be removed in twenty-four hours. If only $\frac{1}{2}$-inch capacity is desired the area may be doubled.

To use the table, find the area to be drained through any point, and choose the size according to the area to be drained and the grade above that point. The tendency is to use larger tile and avoid open ditches, except for large volumes of water. Low-grade sewer-tiles have been successfully used here for main drains. The quantity of water flowing in a drain can be determined by measurement with the trapezoidal weir previously described. A rough estimate of the capacity required can be made by placing a large tile in the ditch and

filling in around it with dirt so that the stream will pass through the tile.

Size of Laterals. — A lateral usually drains a strip only a few rods in width. Unless springs are encountered, a 5-inch tile is large enough for average conditions up to 1000 feet in length. There is so much advantage in the larger tiles that the slight difference in price of 4-inch, compared to 5-inch, tiles does not justify use of the smaller size, except possibly for short lines in heavy soil where there is a large amount of fall. A greater length gives low capacity due to increased friction in the small tiles. In peat or alkali, where laterals are often 440 feet apart, and perhaps 6 feet deep, a 5- or 6-inch tile is needed. The size depends on prevalence of water, or amount of irrigation. Laterals in tide-land should be at least 5 inches.

Grade. — The greater the fall, the greater the capacity. Laterals of 4-inch tiling should have a fall of at least 1 inch in

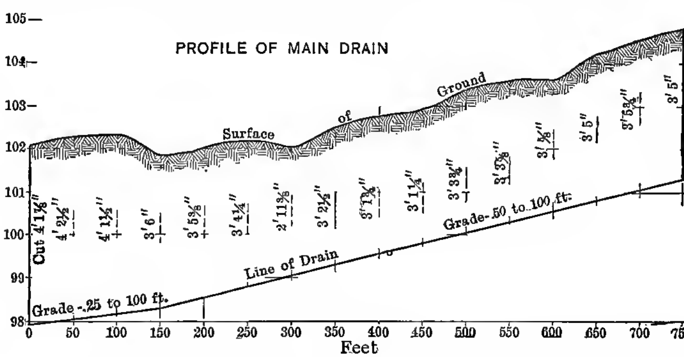

FIG. 24. Profile of the main drain of the system shown in Fig. 20.

5 rods; and twice this amount, or $\frac{2}{10}$ foot for each 100 feet, can usually be secured. A lateral that is to run across a springy slope should have 3 to 6 inches fall for each 100 feet to make the water go through the tiling instead of with the slope of the land. Large tiles may be laid with a fall of as little as $\frac{5}{8}$ inch, or .05 feet in 100 feet. Where the fall is less than 1 foot for 100

feet, the grade should be carefully fixed by the use of a leveling instrument. An effort should be made to avoid changing from a steeper to a lesser grade; and, if such a change is necessary, it is advisable to install a silt-basin.

QUESTIONS

1. Name factors affecting size of tiling and explain their influence.
2. What capacity or coefficient is indicated by outflow measurements? In different regions?
3. What plant-foods are present in greatest amount in drainage-water?
4. Why would runoff result in more soil injury than outflow through underdrains?
5. What are the advantages of large tiles as compared to open drains?
6. What benefits result from using lateral tiles of ample size?
7. Under average conditions how small and how long may a lateral safely be?
8. What is the relation between the size of laterals and the distance between them?
9. What effect has grade on proper size for tiling?
10. What danger is there in changing from greater to lesser grade, and how can this be overcome?
11. What precautions should be taken where there is a steep grade?

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CHAPTER X

CONSTRUCTION OF UNDERDRAINS

When to Tile. — The best season of the year to install a drainage system is late spring. If it is attempted earlier than this, excess water and heavy rains will interfere; and later in the season the soil may become dry and hard, so that it is more

FIG. 25. Tile laying tools. (Courtesy of Iowa State College.)

expensive to work. Marsh land will be least subject to excess water in late summer, while irrigated land may contain less excess water in early spring before irrigation begins.

The Permanent Survey. — While the entire drainage system should be planned before construction begins, it is useless

to set grade stakes for more drains than can be installed during one season, as these will be plowed out, or tramped out by animals, and will need to be replaced in a few months. Where the system is small and there is a fall of more than 1 foot to each 100 feet, the drains may be successfully laid by water-grade, and the amount of tiling needed can be estimated by chaining or carefully pacing out the lines to be installed.

Accurate data and good construction are necessary to secure the highest efficiency in a drain system; and, where the land is at all flat, it will usually pay to get a drainage engineer to test the feasibility of the plan, and set grade stakes or "hubs," so that the tiling can be carefully laid to a calculated grade.

In staking out a drain system, hub-stakes are set at regular 100- or 50-foot intervals, beginning at the outlet. These stakes are set in a straight line, just at the side of the proposed drainage ditch. The "hubs" are driven nearly flush with the surface, and on these the surveyor's rod is held. Guard- or guide-stakes are driven near the "hub" and are large enough to be seen easily. Stakes should be provided in advance.

Where a small amount of leveling is to be done and there is sufficient fall to obviate the necessity of extreme accuracy, a carpenter's level provided with sights may be used for rough leveling work. A fairly accurate farm-level may be bought for about $15, while any farmer or group of farmers with considerable drainage to do could provide a much better grade of level costing $40 to $60.

Fig. 26. Hauling and distributing tile.

Getting the Tiles. — The survey should determine accurately the number of feet of tiling required for the units of the drain system which are to be immediately installed. After the size of tile is decided upon for the different lines, a tile bill may be prepared and bids secured. The tiles should be

ordered in carload lots, if freight is involved, and should be hauled directly from the car to the ditches, being distributed along the trenches, within reach of a tiler standing in the trench. (Fig. 26.)

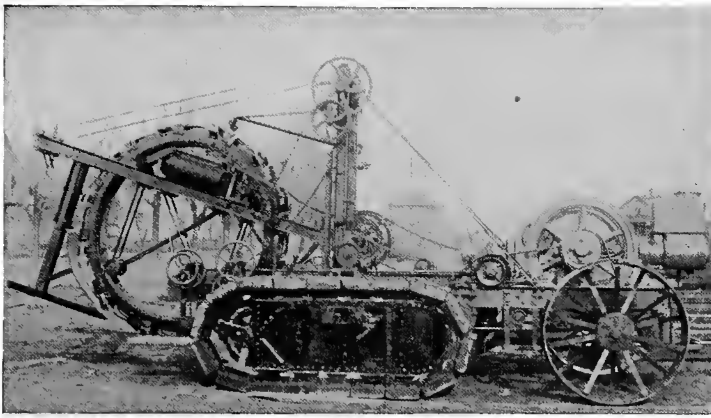

FIG. 27. A traction tile ditcher. Traction wheels may be used instead of tracklaying treads.

Trenching Machinery. — Where there are many long parallel lines of tiling to be installed and the land is reasonably firm and free from structures, stone or hidden logs, a trenching machine may be employed. The wheel or track type of machine, (Fig. 27) may be secured by a district or contractor. Horse-drawn ditchers may save money where labor is scarce and where deep drainage is not required. The Martin ditcher, (Fig. 29) opens up a surface run or removes the surface spading economically, when soil is in condition for plowing and there is plenty of power available. The cyclone ditcher,

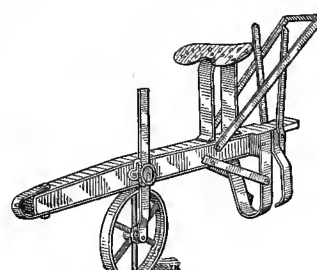

FIG. 28. Ditching plow used for loosening soil in trenches. (Far. Bul. 1131, U. S. Dept. of Agr.)

(Fig. 30) has been used profitably when several carloads of tiling were installed.

The mole-ditcher is a tool which can be set in the soil at the desired depth and drawn through the land on the grade determined, pulling tiles into the opening it forces in the subsoil. When about 200 feet of tile have been placed, the equipment moves forward and is dug in again. The tool is fairly simple and has been successfully used. Lack of labor and increased use of power-machinery increase the demand for trenching by machinery.

Fig. 29. The Martin Ditcher. (Courtesy of Owensboro Ditcher and Grader Co.)

Fig. 30. Cyclone Ditcher

Digging the Trench. — The use of the plow in starting the trench is favored only in tough sod where the work is done by unskilled hand labor. A trench 33 to 36 inches deep can be provided by removing two courses with the tile-spade, and should be started about 11 or 12 inches wide at the top. A three-course ditch will need to be 16 inches wide at the surface. In starting the ditch, a guide string is stretched on the ground at one side of the stakes. At bends, a $\frac{1}{4}$-inch rope should be laid on the ground in a smooth curve. An 18-inch, square-pointed tile-spade is commonly used for removing the first spading. The trench should be kept straight and the sides smooth and plumb. A good spadesman will set the spade a little angling, and will not need to trim the side of the trench much with a spade. A skilled worker will not leave much

loose dirt in the bottom of the trench. If the weather is dry, crumbs should be left in the trench until the second spading is to be dug (to prevent the soil from getting dry and hard). A round-pointed shovel can be used to remove this loose dirt, after which the second spading is dug within an inch or so of the proposed grade. For removing the second spading, some workmen prefer a round-pointed tile-spade, which makes the trench a little narrower at the bottom. The gage-line should be set before the second spading, so that the ditch will in no case be cut below the proposed grade-line. The last inch or two is taken out with a shovel and tile-scoop, leaving a smooth, firm tile-base.

The Use of the Grade-Lath. The depth to dig at each station is measured from the top of the hub-stakes. In order

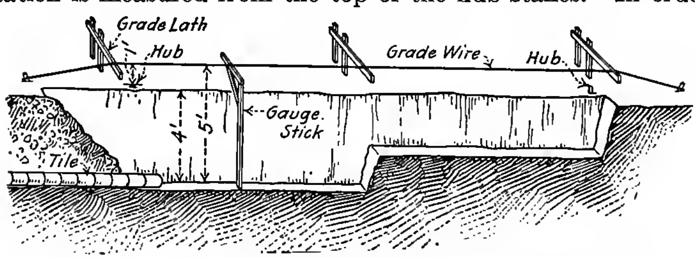

FIG. 31. Sketch showing the use of line and gage in finishing tile trench to an accurate grade.

to dig a trench to grade, or with a finished straight tile-base between these grade points, it is best to use a gage-line and gage-sticks, as shown in Figure 31. Grade-bars are set over each hub-stake at a uniform and convenient distance above the proposed tile-base. A wire is stretched over these grade-bars a uniform distance above the proposed grade-line and parallel to it. If the grade-bars are 4 feet above grade, the ditch should be trimmed out until a 4-foot gage-stick, when held in a vertical position, will just reach from the string to the bottom of the trench. To determine the height at which to set the grade-bars we subtract the depth of the cut from the length of the gage. Grade-bars may be set across the ditch, or at one side with a cross-arm extending out even with the

near edge of the trench. A No. 18-gage galvanized wire makes a good gage-string, as it is light and strong as well as durable. In cutting through high ridges, a longer gage may be required. The gage-line must be kept tight. The arrangement of grade-bars is illustrated in Figure 32. The following table for con-

FIG. 32. Finishing trench to grade and laying tile. (Courtesy Iowa State College.)

verting decimals of a foot into inches is convenient for converting the cut and gage-height to give to farmers.

TABLE XIV. — EQUIVALENT VALUE OF INCHES AND DECIMALS OF A FOOT

In.	0	1	2	3	4	5	6	7	8	9	10	11
0	.00	.08	.17	.25	.33	.42	.50	.58	.67	.75	.83	.92
$\frac{1}{8}$	.01	.09	.18	.26	.34	.43	.51	.59	.68	.76	.84	.93
$\frac{1}{4}$	.02	.10	.19	.27	.35	.44	.52	.60	.69	.77	.85	.94
$\frac{3}{8}$	.03	.11	.20	.28	.36	.45	.53	.61	.70	.78	.86	.95
$\frac{1}{2}$	.04	.13	.21	.29	.38	.46	.54	.63	.71	.79	.88	.96
$\frac{5}{8}$	.05	.14	.22	.30	.39	.47	.55	.64	.72	.80	.89	.97
$\frac{3}{4}$	.06	.15	.23	.31	.40	.48	.56	.65	.73	.81	.90	.98
$\frac{7}{8}$	.07	.16	.24	.32	.41	.49	.57	.66	.74	.82	.91	.99

Laying the Tiles. — Tile-laying should start at the outlet and proceed up the stream, as soon as the trench is finished to grade. A careful workman can be selected to handle the tile-scoop and shovel just ahead of the tile-layer. A tile-scoop should leave a firm tile-base and a little running water will help to make the tile-base smooth. A carefully finished trench facilitates the laying of tiles. The grade should be tested for every length of tile; and the pieces should be placed in a straight line, with the long side up, so that the joints fit tightly at the top side and are nearly flush at the lower inside edge. An opening of $\frac{1}{8}$ inch is allowable; but larger openings should be covered with fragments of broken tiles, called "bats." The tiles may be rotated to fit, and imperfections in tiles may be taken advantage of in making slight turns. Ill-shaped, cracked, and broken tiles should be discarded. Where quicksand or muck makes a soft bottom in the trench, it is best to lay the tiles on a board or in a "V" trough. Sometimes the trench may, with advantage, be excavated below grade and back-filled with gravel. In extreme cases concrete may be used.

Fig. 33. Laying thirty inch tile by means of derrick and windlass.

Fig. 34. Filling the tile trench with a plow. (Courtesy Iowa State College.)

Clay, burlap, or straw may be used to prevent quicksand entering the joints. Curves can be fitted by carefully chipping off the inside edge of the tile with a chisel and hammer. The "Y's" can be constructed, but it is best to order these when ordering the tiles. Inspection of the drains before filling should be made by the landowner, to see that no inferior pieces have been used, that there are no wide joints which appear unprotected, and that the tiling is laid true to grade. A level can be used to test the line, at frequent intervals, for dips or swells in the grade. If muddy water is encountered in the trench, it may be dammed up and held back, until it can be passed through the tiling in quantities sufficient to avoid silting. Where the ditch banks are unstable, it may be necessary to resort to curbing or to blind in the tiling each evening. Precautions should be taken against damage by storms occurring at night during construction.

Filling the Trench. — After inspection, tiles are blinded by a workman who stands beside the trench and shaves mellow dirt from the sides of the ditch, with a spade. A layer of mellow dirt, 3 or 4 inches deep, prevents the tiles from getting out of line. Plowing off the shoulders of the trench, with a plow that is equipped with long eveners, will put the surface soil in the lower part of the trench. Other tools used for filling trenches are V-crowders, which are shod, light road-drags, and light road-graders, (Fig. 35). Filling is more readily accomplished before the dirt has become compact and settled.

Tiling contracts are frequently let at a stipulated price per 100 feet or per rod. The contractor usually furnishes the tools and the landowner furnishes the tiles to be used along the proposed drain. Whether board is to be provided, and whether the trench is to be completely filled, should be stated in the agreement. The contractor is usually required to begin at the outlet to lay true to grade, and to pursue the work with due diligence. Arrangements are frequently made for securing pay for a part of the finished work during construction. While the data are fresh in mind, and before the tiles are hidden, a sketch should be made of the tile-lines, showing their length

and depth, and the distance between them. A compass can be used to locate the bearings of different tile-lines; and permanent landmarks, such as trees and property corners, should be referred to, so that any part of the drain system can be located in after years. This is a great help in locating any obstruction or in constructing any additional laterals later. Maps may be simple, but should be definite. A memorandum of the items of cost should be filed with this map.

FIG. 35. Filling the tile trench with a road grader. (Courtesy Iowa State College.)

There are numerous details which must be attended to in tiling if the drain system is to be permanently successful. A few important points upon which numerous inquiries have been received are here discussed.

Outlets. — It is of primary importance that the drain system have a good outlet. It has been said that a drainage system without an adequate outlet is like a man who is "all dressed up with no place to go." Where the outlet is submerged, the velocity of the outflow is checked, and sediment is likely to collect and clog the drains. The water should have a free spillway at the outlet. A partly submerged outlet can be kept clear if there is a considerable volume of water and velocity of flow, and if a barrel or box is provided for collecting sediment and is cleaned out, perhaps twice a year. The submerged outlet, however, is not desirable, as the land will never drain below the level of the water in the outlet.

The outlet pipe or tile should be vitrified, or else a corrugated culvert should be used. Such material is not affected by freezing or the tramping of animals. The end of the outlet should be screened, as in Figure 36, with $\frac{1}{4}$-inch iron rods, placed about 1 inch apart, to prevent rodents from entering the tile. Where the outlet is submerged at times, it is advis-

able to provide an automatic flap-gate, hinged at the top so as to close during times of high water, or when the drainage ceases in the summer. A small bulkhead should be provided at the outlet to force the water to run out through the tile, instead of cutting out around it. This will also retain the earth bank and serve as a monument to mark the location of the outlet. The footing should extend out below the tiling, to form an apron on which the tile may discharge without causing erosion.

FIG. 36. Tile outlet and protection. (Courtesy Baar & Cunningham, Portland.)

Silt-Basins. — Silt-basins are small cisterns or manholes in the drains, extending to the surface from a foot or more below the tile-grade. They are usually provided at fence corners, where two or more lines of tiling join. Silt-basins afford a means of collecting and cleaning out silt; they help to collect surface flood-water quickly, prevent the drain from becoming clogged, and may sometimes be arranged to afford watering-places for the stock. Silt-basins also permit inspection of tiling, and may increase the head of water on the outlet drain in time of high water. A small silt-basin can be constructed by placing a 12-inch sewer-tile, having the required outlets, on end. For larger silt-basins, brick or concrete may be used.

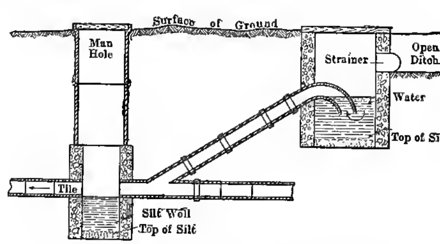

FIG. 37. Surface inlet and silt basin.

At the Oregon Experiment Station, it was found convenient to construct silt-basins or manholes of concrete (See Fig. 37). The soil is used for the outer form, and the inner form is made of

staves, like a silo, one of the staves being beveled so that it can be removed after the concrete has set. The form makes the manhole 5 feet deep and 3 feet in diameter, with a 20-inch opening in the top, which may be covered with a concrete lid. The walls are about 4 inches thick. The tile-lines are already in place when the silt-basin is constructed; and the form sets tightly against the tiling emptying into the silt-basin.

A surface inlet to the silt-basin may be provided. The water should be screened and brought in on a grade, to prevent roiling the sediment with the water in the silt-basin. A few cubic feet of gravel or broken tile in the trench will make a fair inlet at the head of the drain. Surface inlets are apt to clog or admit silt, and should seldom be employed. Straw or sods in the trench may serve better to aid the entrance of water into tile (Fig. 37).

Relief Wells. — Wells are frequently used to collect the water in a deep gravelly stratum where it is under pressure, as in irrigated or seepage land, and to bring it up to within reach of a conducting drain (Fig. 38). Short collecting laterals may lead to this well; and occasionally a wind-mill may be used to elevate water to the outlet tiling, where elevation for gravity drainage does not obtain.

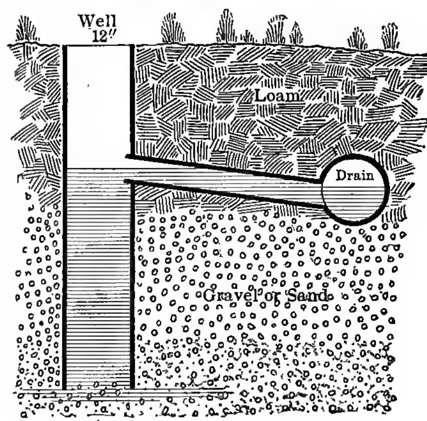

FIG. 38. Relief Well.

Junctions. — The laterals may be laid out perpendicularly to a main drain, but should join the main with a curve, so that the connecting tile or "Y" will have an angle of about 30 degrees, as in Figure 39. The curve should have a radius of about 5 feet. There should also be a drop where the lat-

eral joins the main, to permit free discharge into the main drain.

Obstructions. — The principal obstructions occurring in tiling are small animals, roots and silt (Fig. 40). Protecting all exposed ends of the tile system with screen or broken pieces of tile will prevent small animals from entering. Roots of trees, such as willow, elm, tamarack and soft maple are troublesome. Cultivated plants, such as alfalfa, grape-vines and kale also give trouble where spring-water runs in a tile-line throughout the growing season. Water-loving trees within 20 or 25 feet of the drain should be girdled or cut down, or else the tile should be cemented at the joints where the drains pass within this distance of the trees. Silt will be less troublesome in large tiling. Small tiles must be laid true to grade to prevent trouble; and the carrying capacity will be greater, and friction will be less, if the lower inside lines of the tiles are flush.

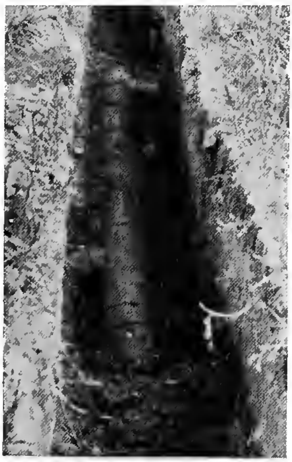

Fig. 39. View of Y-tile in trench properly laid.

Fig. 40. Drain filled with roots from adjoining willows. (Courtesy Iowa State College.)

To locate obstructions, dig holes in several places over the tile. A tile-map and an end-gate rod will be of value in looking up and probing for tile-lines. Below the obstruction the water will not rise in a dug hole but will fall away into the tiling. Above the obstruction the water will rise and stand

in the hole. The tiles can be uncovered above and below the obstruction, and cleaned out with a jointed sewer-rod or with a long, limber pole or a wire cable frayed out into a wire brush at the end.

A tile-line, to be permanently successful, must be given some attention. Inspection and cleaning out of outlets and silt-basins should take place at least twice a year, in the fall before the rains begin and again during the highest water of the season.

QUESTIONS

1. What seasons are suitable for installing a drainage system?
2. What data should the permanent survey provide?
3. Under what conditions would ditching machinery be suitable?
4. What different types of machines are in use?
5. Describe the procedure in constructing a ditch with spades and shovels?
6. Under what conditions should a plow be used?
7. How wide should a 3-foot trench for lateral tiling be started at the surface?
8. Describe the method of setting the grade-line.
9. How is the grade-lath used in laying to grade?
10. What is the tile scoop or "crummer," and how is it used?
11. Why do we begin at the outlet in laying tiles?
12. Describe operations of laying in a straight line? Around a curve?
13. How is a lateral joined to the main tiling?
14. How may quicksand be kept out of tiling?
15. What is "blinding in," and how is it accomplished?
16. Describe a good method of back-filling.
17. What items should be included in a tiling contract?
18. Describe the construction of a good outlet.
19. Under what conditions should a sluice-gate be provided?
20. What purpose may a silt-basin serve, and how is it constructed?
21. Describe the construction of a surface inlet? A relief well?
22. What is the purpose of a relief well, and how is it built?
23. What are the common causes of obstructions in tiling?
24. How may obstructions in tiling be located and removed?

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CHAPTER XI

COSTS AND PROFITS OF TILE-DRAINAGE

THE cost of drainage varies greatly with the kind of soil, size of tiles, thoroughness of drainage, method of construction, and labor conditions. It is necessary, first of all, to determine the number and size of tiles required before making definite estimate of cost. Cost of drainage has advanced somewhat, but not as much as prices of crops or value of productive lands.

Costs. — The cost factors to be considered in the tile-drainage system are (1) cost of materials, (2) cost of labor, (3) cost of delivery of materials, (4) cost of depreciation of the necessary plant, (5) cost of financing the contract, (6) probably damage claims and legal expenses, (7) rights of way, and (8) engineering and contingencies.

Costs of Materials for Tile-Drains. — The principal materials needed for the construction of tile-drains are tile, gravel, cement, grates, sewer-pipe, corrugated pipe and specials, such as tile Y's and sewer-pipe T's. As a rule the cost of tiles delivered on board the railroad cars at the factory station is fixed by the published price of the tile companies. These published lists are usually subject to a discount, sometimes as great as 50 per cent, for cash.

The Tile Bill. — It is necessary, first of all, to determine the number and size of tiles before making a definite estimate of the cost. From the permanent survey a tile bill should be arranged, showing the number of feet of different sizes of tile required for each main and lateral and the total number of different sizes to order. In addition to the general tile bill, a separate bill of pipe specials (Y's and T's), corrugated iron, or vitrified clay outlet pipe, gratings, etc., can be made up. The tiles should be ordered in carload lots for delivery to the

nearest railroad point, and the shipper should be responsible for breakage in shipment. Table VI shows the comparative average cost of clay and cement tiles, sewer-pipe, corrugated pipe and grates, discount having been subtracted and pre-war prices used.

TABLE XV. — PRE-WAR COST OF MATERIALS FOR TILE-DRAINS. (Middle West) (June, 1917)

Diameter of pipe in inches	Clay Tile		Weight in lbs. per ft. tile	Cement Tile		Sewer-Pipe	No. ft. per ton	Average car-load in ft.
	Cost per 1000 ft. Illinois	Oregon		Cost per 1000 ft.	Weight in lbs.	Cost per ft.		
3	17.00	18.00	5	—	6	—	400	7500
4	20.00	22.50	$6\frac{1}{2}$	20.00	$7\frac{1}{2}$		334	6500
5	26.00	30.00	10	25.00	11		250	5000
6	37.00	42.00	12	35.00	15	0.09	182	4000
7	40.00		15	43.00	18			
8	65.00	75.00	18	50.00	21	.15	111	2400
10	85.00	110.00	27	75.00	32	.20	80	1600
12	125.00	150.00	36	100.00	40	.24	60	1000
14	195.00	210.00	48	165.00	50		56	800
15	230.00		50		60	.37	38	500
16	260.00	250.00	60	240.00	85		28	400
18	360.00	350.00	70	300.00	100	.56		
20	500.00		90	360.00	116	.75		
22	575.00		110	420.00	142	.90		
24	675.00		124	540.00	186	1.05		

Gravel and Sand. — The cost of gravel and cement will depend on local conditions. Gravel may often be obtained at a nominal cost at a nearby pit, so that the hauling will be the principal item.

Cement is sold by the bag or barrel. The price depends on the distance from the factory and the purchasing value of the dollar at the particular time. At present (1919) the prices of cement by the barrel in various cities of the United States are as follows:

TABLE XVI. — CEMENT PRICES AT DIFFERENT POINTS, 1918

	Current	One Month Previous	One Year Previous
Boston	$3.67	$3.59	$2.37
Cedar Rapids	2.68	2.68	2.48
Chicago	2.45	2.45	2.21
Cleveland	2.72	2.72	2.44
Cincinnati	2.80	2.80	
Dallas	2.90	2.80	2.40
Davenport	2.64	2.64	2.40
Denver	3.67	3.67	3.20
Detroit	2.68	2.68	2.40
Duluth	2.60	2.60	2.51
Indianapolis	2.62	2.62	2.38
Jersey City	3.64	2.99	2.16
Kansas City	3.30	3.30	2.44
Los Angeles	3.38	3.38	2.30
Milwaukee	2.56	2.56	2.33

It may be necessary to make an allowance for freight in addition to the prices indicated in the table. The minimum weight for a carload of tiles is 30,000 pounds, and the average weight of a carload is about 40,000 pounds. As tiles are rather bulky, a ton makes a fair wagon-load. About 500 4-inch tiles or about 200 6-inch tiles can be hauled at one load. Two men with wagons, when hauling to the same field, can assist each other in loading and unloading.

Trenching. — Digging the trench, laying the tiles and blinding in with 3 or 4 inches of mellow dirt commonly costs, in the Willamette Valley, from $0.25 to $0.40 a rod. The latter price frequently includes filling the trench. Reports on tile-drains in the Willamette Valley, aggregating 100 miles of tiling, show that the average cost for digging and laying for each rod has been $0.30. The cost of digging and laying varies greatly with the kind of soil, size, depth of tiling, and difficulties encountered. Table XVI, arranged by Professor E. R. Jones of Wisconsin, shows the relation between depth, size of drain and cost for each rod.

TABLE XVII. — APPROXIMATE COST PER ROD OF DIGGING TRENCH, LAYING TILE, AND BLINDING

Size of Tile	Depth in Feet			
	3	4	5	6
4 inch	$.30	$.50	$.80	$1.25
5 inch	.35	.55	.85	1.30
6 inch	.40	.60	.90	1.35
8 inch	.45	.65	.95	1.40
10 inch	.50	.70	1.00	1.45
12 inch	.55	.75	1.05	1.50

Filling the trench with a plow or road-drag has been done in this locality for $0.10 or $0.12 for each hundred feet. Where the filling must be done by a more laborious process, it may cost $0.20 to $0.25 a hundred feet. To these items should be added 5 per cent for surveys and superintendence, or 10 per cent, including outlets, silt-basins, tools, and miscellaneous expenses.

The tiling required for each acre, if laid in parallel lines and 4 rods apart, will be 40 rods; if 6 rods apart, 30 rods of tiling will be required. At a total cost of $0.75 to $1.00 a rod for laterals, this would mean $30 to $40 an acre for thorough drainage of the wettest areas on the farm. It rarely happens that more than 25 per cent of the average farm will require such thorough drainage. More frequently, wet swales or springy spots are drained with a random system of tile-lines, making it possible to work the whole field at one time, as well as increasing the production of the low area. In order to direct attention more fully to the cost and profit connected with drainage, a few typical examples of actual costs and results from different sections of the state are here given.

Results from Tile-Drainage in Oregon. — A drainage system was installed by the United States Government in 1908, on a 72-acre field of " white land " 1 mile south of Albany. From 3- to 10-inch clay tiles were used; the depth varied from 3 to 4 feet, and the distance between drains was purposely varied

from 60 to 150 feet. Grades ranged from 0.2 foot to 0.5 foot for each hundred feet. The entire cost of draining the 72 acres of land was $19,292.79, or $26.80 an acre. Drainage has made it possible to raise clover on this land, and the amount of

Fig. 41. Land before draining at Astoria Experiment Station, Oregon.

underdrainage is gradually increasing each year. The system is declared a success by the owner of the tract, who estimates that the land is now actually worth, for farming purposes, four times what it cost before being drained.

Nearly twenty-five years ago, a drain system was installed in a " white land " area on the College farm at Corvallis under the direction of Professor French. The professor states that before being drained this area was so wet that it produced little but wild oats, tar-weed, sorrel, and cattails. Since it was drained, its yields have steadily increased. Last season, about 5 tons to the acre of clover hay was produced on this land. The drains have paid for themselves over and over, and are more effective today than ever.

Project No. 40 is installed near Troutdale. The field contained 7 acres of peaty loam, too wet to farm, and producing only a marshy growth which provided a little pasture. The installation of the drain system entailed the following expenses:

Tiling, 5000 feet, 3-inch, 4-inch and 5-inch, costing ...	$129.00
Freight Bill	12.00
Hauling of 12 loads at $2.00 a load	24.00
Digging 306 rods at $0.30 a rod	91.80
Total	$256.80
or $34.97 an acre	

FIG. 42. Same land as Fig. 41, after drainage growing a crop of oats and peas.

The owner states that until the land was drained it was not worked, on account of wet places. The drain system was installed in 1912, and, the following winter, the main ran full for several days at a time. The next year, according to the owner, the piece produced $176 worth of potatoes to the acre. In 1914, this same field threshed out 64 bushels of oats to the acre. A stand of clover has been secured, which was impossible before draining. The owner says, "We have already received full returns for our investment."

Project No. 43, an alkali area, is located in Crooked River Valley, 3 miles east of Prineville. Before this land was drained, it was regarded as practically worthless, because of the presence of black alkali in the soil. Four acres of black loam were drained with the following costs:

Tiling, 1500 feet	$35.00
Freight from Portland to Redmond	72.00
Hauling tile to ranch	17.50
Labor, 7 days at $2	14.00
Total	$138.50
or $34.63 an acre	

These figures are given by the owner, who says, "The tiles were laid 60 feet apart and 3 feet deep and drained the area easily at that distance. If placed 4 feet deep and 100 feet apart, the tiling would have drained 6 acres instead of 4. We were unable to get the latter depth owing to difficulty in securing an outlet for that level. Securing the tiles in carload lots would have reduced the expenses to $89, or $22.25 an acre.

"Before the land was drained, the crop in 1914 for the 4 acres was 20 bushels of barley or 5 bushels an acre. The crop in 1915 for the 4 acres was 278 bushels of wheat and barley, or 69½ bushels an acre. Placing a value of $0.80 a bushel on this crop, the result is $222.50, which, less the cost of draining, $138.50, equals $83.90 net gain this year from the above operation. From these results, we firmly believe that tile-drainage is an unqualified success. This 4-acre tract we tiled only as an experiment, and we intend to drain 40 acres more as quickly as possible. There are few investments which pay so well."

QUESTIONS

1. What are the elements that enter into the cost of a tile system?
2. What materials are used?
3. How should the tile bill be arranged?
4. Why are tiles ordered delivered and in car lots?
5. About how many tile will there be in an average carload?
6. What is a reasonable price for tile laying per man-hour?
7. Explain the effect of depth on cost of trenching.
8. Compare the cost of trenching by hand and with machine.
9. How does gravel or hard-pan affect the cost of trenching?
10. What is a reasonable percentage to allow for engineering expense?
11. Give examples of successful drainage projects.

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CHAPTER XII

DEVELOPMENT OF WET LANDS

Reclamation of marsh lands consists of three operations: (1) construction of community outlet ditches, (2) field or farm drainage, and (3) subjugation of wild growth, removal of foreign material, and preparation of the soil for cultivation.

Fig. 43. A large stump cracked with dynamite before pulling. (Courtesy American Society of Agricultural Engineers.)

Our wet, marshy and overflowed lands offer a comparatively safe field for development with a view to increasing food production or providing homes for returned soldiers. To be most successfully reclaimed, such lands should be brought promptly into a good state of production, in order to avoid interest charges and facilitate operation of tiling. Frequently such lands return the entire cost of reclamation with the first crop.

Time, labor, and expense are required to eliminate trees, stumps, brush, stones, tule, or even coarse peat from about 20 per cent of our wet lands. Drainage may render saw-timber or stove-wood accessible, and the sale of this material may help to pay the cost of clearing. Brushing with an axe

and bush-scythe, or with goats, may be practised at times while stumps are decaying; and grass may be seeded in and the

FIG. 44. A horse power puller in use. (Courtesy American Society of Agricultural Engineers.)

FIG. 45. A device for piling stumps. High piles burn best. (Courtesy American Society of Agricultural Engineers.)

stumps allowed two to five years to decay before their removal. Stumps can then be removed by a stump-puller or engine and cable, or they may be burned by directing the fire through

an auger-hole or char-pitting furnace. Dynamite, carefully used, will crack the stumps and jar dirt loose after pulling, when stumps can be piled with a boom-pole into tall compact piles to facilitate burning.

The rank growth of tule, or swamp growth, may be subdued by carefully burning over the surface when the soil is wet, so that fire will not extend more than a few inches below the surface. This overcomes the rawness of the soil, adds some available plant-food, and tends to correct growth of moss and to

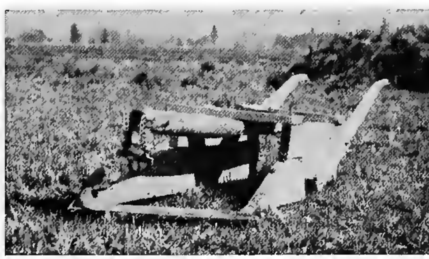

FIG. 46. Rush cutter used at Tillamook, Oregon.

help expose roots and logs, which may need to be removed before cultivation. Open ditches for laterals will frequently be used during this process; and, as the marsh settles, more permanent underdrains may be put in. These underdrains can be extended as needed to perfect drainage, so that the more intensive crops can be grown where climate and market facilities permit.

Cultivation. — The use of a rush-cutter, or sled to which knives are attached, will aid in scalping off rushes on low lands. The rushes can then be bunched up and burned before plowing. A plow with a broad, sharp share should be used in breaking marsh sod. A 24-inch plow, drawn by a caterpillar engine, was seen in use on marsh land at the Wisconsin Experiment Station. This outfit inverted the furrow more than in ordinary plowing, covered rubbish and firmed the soil, so as to aid decay. Thorough discing is necessary to prepare a seed-bed on new breaking. Peaty soil is loose when dry; and a com-

pactor, such as the double corrugated roller or multipacker, is necessary to firm the soil and bring moisture to the seed-bed. Seeding should be done early in spring. A grass mixture can be seeded and brushed in on stump land to attract stock and afford pasture while stumps decay.

FIG. 47. Cranberries growing on peat land.

Choice of Crops. — On peatland a mixture of Alsike clover and timothy has been successfully seeded into the ashes after marsh vegetation has been burned. Feeding out clover hay on the land without plowing up has established Alsike in some marsh meadows. A fairly permanent meadow can be established on low, wet areas by using a mixture of grasses such as blue-grass, English rye-grass, timothy, redtop, and white or Alsike clover.

FIG. 48. Truck garden on tile drained lands at Astoria, Oregon.

On better-located areas, after the first breaking, rank feeding crops like oats, barley, flax, or corn should be grown for a

year or two; then, if the water-table is at sufficient depth, the Alsike clover will do well to maintain a moisture supply. Canary-grass and bent-grass make excellent pasture, and have been used on the peat lands near the Pacific Coast.

FIG. 49. Splendid crop of onions grown on reclaimed peat bog near Salem, Oregon.

When sod-bound meadows are harrowed after several years, they should be re-plowed and used for a couple of years for grain and row crops, such as roots, then seeded down again.

Thoroughly drained and subdued peat land, where located within reach of markets, is used for potatoes, celery, onions, roots, and other leafy truck-crops which thrive on soils rich in nitrogen. The cranberry is also produced in certain localities on this type of land.

Fertility in Marsh Soils. — Peaty soils are apt to be raw when first drained, and may respond to manure or complete fertilizer. When subdued, these lands usually have an abundance of nitrogen and humus, but frequently respond to applications of potash. Fertilizer trials on muck soils in different sections of Oregon have not shown much benefit from the use of potash; but superphosphate and manure have frequently caused increased yields. Potash is more likely to benefit deep peat that

has received little inorganic material by in-wash from adjacent uplands.

Treatment of Heavy Land. — Experiments are under way to determine the best treatment for "white land" on the Oregon Experiment Station farm. The whole field is seeded to one crop each year and a three-year rotation is employed; viz., spring barley, followed by clover, one crop a year, then a cultivated crop, such as corn. The effect of lime, manure, green manure, and combinations of these treatments is tried out on duplicate plots, and their value is judged by the use of check-plots.

Fig. 50. Celery grown on reclaimed land in Lake Labish drainage district, Oregon.

In a new experiment field, straw and gravel are being compared as to their cost and effectiveness in helping the water to enter the tiling. The results with each material are being measured and judged by the comparative yield and the relative amount of runoff.

Operations that Aid Drainage. — From studies already made, it appears that the following things can be done to aid tiling in collecting water in "white land" or other retentive soil:

(1) In draining a retentive, saucer-like area, the protecting drains should be laid out so as to collect seepage-water or surface-water before it reaches the retentive soil.

(2) Catch-basins should be used in the upper side of the field, or at points where the surface-water is apt to run on to the heavier soil.

(3) After the tiling has been laid and lined, the trench should be allowed to remain open a few weeks, if possible, so that air can come into contact with the subsoil and cause it to slack and crumble.

(4) In filling the trench, it is advisable to put in sod or

straw, and then the top soil immediately over the tiles. Straw will decay, thereby increasing the open space, whereas gravel may silt up. However, where the grade is steep, gravel would protect tiling from washing out better than straw. If the sticky, sub-surface soil is used, it must be put in the top of the trench.

(5) When it is dry enough to crumble, the land should be plowed deeply.

(6) After the installation of drainage, lime will become more effective and will aid in mellowing the soil.

(7) Drainage and liming will, in most cases, make it possible to raise clover on the land. Clover roots will penetrate the drained soil and will be of great value in loosening up our valley land so that water can pass through and get into the drains.

(8) Where possible, the land should be plowed in such a way that the dead furrows will fall directly over and parallel to the laterals, giving the surface a slight slope toward the laterals. Surface-water that collects in these dead furrows will pass into the laterals more readily. If it remains on the surface temporarily, and there is ample tile capacity, occasional catch-basins can be provided on heavy soil to aid in sending water into the drains underneath.

Clover should be grown on the heavy land about each third year in rotation with grain and cultivated crops or other similar crops. A decidedly larger relative outflow has been observed in the wet season following a clover crop, and water has disappeared more rapidly. With manure and clover plowed under, one in each rotation, the yields of these crops on our tiled land can be built up to compare very favorably with the best uplands.

Treatment for Alkali Lands. — Alkali land, after being drained, can be improved, where water is available, by late fall irrigation to flush off accumulated surface salts. Shallow open ditches may help to remove heavy alkali crusts quickly. In one or two seasons irrigation will usually remove and disperse heavy alkali to such an extent that, by deep plowing, hardy crops, such as rye or sweet clover, can be established.

It may take from one to three years to complete the reclamation of these lands, depending upon the amount of alkali and the retentiveness of the soil. Such crops as rye or sweet clover, if plowed under, will supply humus and nitrogen and loosen up the soil so that moisture conditions may be more readily controlled. During the process they may provide some return in the form of pasturage. The alkali lands, when thoroughly reclaimed, are usually strong in the necessary plant-foods and suitable for alfalfa and the other staple crops of the region.

Care of Tile Systems. — Outlets, channels, silt-basins, and inlets should be inspected and cleaned, if necessary, before the season of heavy precipitation and after heavy storms. Any obstructions in tile-lines should be located and promptly removed. The land should be watched and tile-lines extended, if necessary, till the system serves the entire wet area.

The treatments above described are calculated to assist in loosening up and aerating the drained soils and to assist water in entering the drains provided. The legumes and manuring crops suggested will also supply humus and nitrogen, which are ingredients none too plentiful in much of the " white land " and irrigated and alkali land. This treatment would pave the way for cash crops and make it possible to get the greatest possible benefit out of the drains installed, and so render the enterprise thoroughly successful and profitable.

QUESTIONS

1. What three operations are included in reclamation of marsh land?
2. How can rank tule growth be removed without serious injury to the soil?
3. How may rushes or tussocks be killed out and removed?
4. What machinery is suitable for breaking and firming marsh land?
5. What crops are suitable for newly broken marsh land?
6. What legumes and grasses are adapted to reclaimed marsh land?
7. In what proportion are the important plant-food elements present in peaty soil?
8. What fertilizers are most likely to benefit swamp soils?
9. What treatments will aid percolation into tile in heavy drained soils?

10. What treatments will aid in restoration of structure and productiveness of tiled alkali soil?

11. What precautions should be taken to maintain tile systems after installation?

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PART II. — DISTRICT DRAINAGE

CHAPTER XIII

DRAINAGE DISTRICTS AND DRAINAGE LAWS

The greatest obstacle encountered in draining large areas of nearly flat-lying land is the lack of an outlet for the individual farm. In these areas, a community interest is imposed by nature upon the landowners. To secure a community outlet ditch, where many owners are concerned, it is necessary to organize by law a practical drainage district.

The object of such a law is to make possible the construction of outlet drains for the community, through coöperation of the owners benefited, and to meet the cost by equitable assessment. The ultimate object is to fit the land for more profitable production. The district law prescribes a definite method of procedure whereby communities can organize, under proper governmental authority, to drain for the public welfare, issue bonds, and assess costs.

Fundamental Principles. — The principles involved in the undertaking are as follows: (1) It must be coöperative and optional. (2) It must be for the public welfare. (3) Assessments must be adjusted in proportion to benefits. The benefits should be more than the cost, *including* damage and overhead expense of the district, legal expenses and an amount which will earn sufficient interest to cover the cost of maintenance. That is, benefits must be sufficiently in excess of costs to provide a maintenance fund. (4) The right of way must be paid for. (5) The owner should have the right of appeal, if necessary, to secure equitable assessments. (6) The right of outlet should be perpetual and should be attached

to the land title. (7) The drainage tax should be first lien on the land.

Such a law, to be successful, must, of course, conform to the laws of the state. The assessors should not be related to the owners by blood or marriage; the benefits should be more than cost plus damage; the bonding should be decided upon only by the owners of the land in the district. A drainage district may issue and sell securities or bonds against the lands included for purpose of borrowing money at moderate interest rates for a long period of years, during which time the increase in crop yields will enable the landowner to pay off the loan in moderate installments.

Drainage Laws of Different States. — The first practical district drainage law was enacted by Illinois, and this was followed by similar laws in other Corn Belt States. The laws were improved by amendment from time to time, until they became complicated. The National Drainage Congress appointed a commission to draft a uniform and model district drainage law in 1912. The modern law drawn up by this commission was promptly adopted by the State of Missouri, where drainage bonds are now said to sell at or above par. Partly through the efforts of the State Agricultural College, the State Engineer's Office, and the State Drainage Association, a drainage law patterned after the model drainage law, refitted to Oregon conditions, was passed by the Oregon legislature and became effective May 22, 1915. This law was recommended by the leading drainage authorities in the United States. It has recently stood the test of the United States Supreme Court. Some preliminary survey work is necessary before a petition for a district can be prepared. A map showing the individual ownerships, chief road, general topography, texture of wet areas, and plan of drainage, should be prepared. The successive steps necessary to secure outlet ditches under such a law are shown diagrammatically in Fig. 50. The principal features of the law are as follows:

(1) The owners of fifty per cent or more of the acreage in the proposed district must petition the county court, which

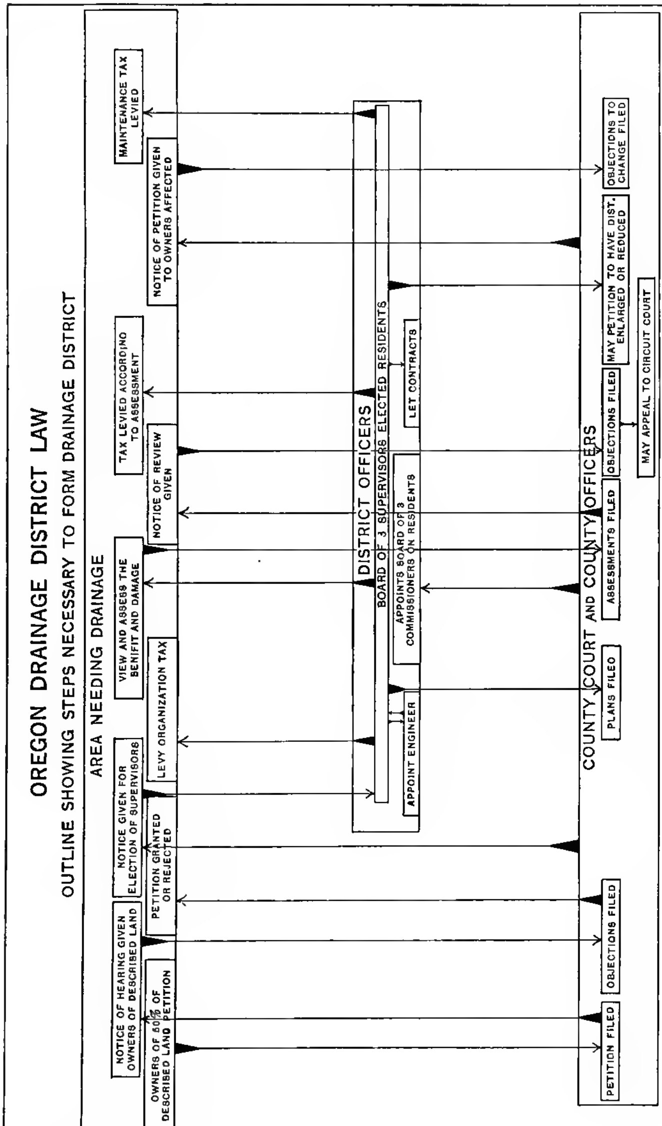

FIG. 51. Diagram illustrating the Oregon drainage district law.

has general supervision of drainage districts, for the organization of a district. The petition must contain:

(*a*) the name of the district;
(*b*) the boundary lines of the district, or description of all the lands constituting the wet areas;
(*c*) the total acreage;
(*d*) the names of landowners within the district as shown by the county records;
(*e*) an allegation that the proposed drainage project is for sanitary or agricultural purposes and of public benefit;
(*f*) an allegation that the lands included are properly included and will be benefited;
(*g*) an allegation that benefits will exceed damages;
(*h*) an allegation that the district plan is a proper method of accomplishing reclamation;
(*i*) a brief statement of the plan of reclamation;
(*j*) an agreement that signers will pay all expenses of organization or attempted organization;
(*k*) a petition asking that the lands be organized.

The petition must be verified by affidavit. It must state the general plan of reclamation and give authoritative evidence that the drainage proposed is regarded as feasible.

(2) A formal notice of petition and of hearing must be sent by the county clerk to all the landowners. The county court considers the petition and any objections filed and will establish the district or dismiss the petition.

(3) After approval of the petition, the county clerk calls a meeting of the landowners for the purpose of electing a board of three supervisors, who must be landowners in the proposed district, to have general charge of the enterprise, and to hold office as determined by lot from one to three years or until their successors are elected and qualified.

(4) The board elected has power to appoint a drainage engineer and to levy a tax of not more than $0.50 per acre, for the purpose of paying expenses incurred or to be incurred in organizing the proposed district. The board files with the county clerk a plan of reclamation prepared by the engineer,

and may petition the county clerk to alter the boundaries of the district. The board is required to keep a record of its proceedings.

(5) The county court appoints three commissioners who are disinterested landowners to make the assessments of benefits and damages and file a report with the county clerk.

(6) Property owners are notified of this report by publication and may file acceptance with the county court.

(7) The drainage board must levy the assessments, let contracts, and secure the construction of all drainage work; they may issue bonds and collect the assessments in annual installments. They may also levy a maintenance tax and define terms whereby existing drains may be connected with the ditches in the district. A detailed estimate must be prepared before active construction can begin. Benefits should exceed costs, and costs should include damages, construction, engineering, and legal services.

Laws of the various states differ in several particulars, including the following:

(1) The proportion of acreage of owners who must petition
(2) The manner of excluding lands from the district
(3) The number of directors
(4) Whether vote is by average or by individuals
(5) The provision for governmental supervision

The new Oregon law places the important work in the hands of the landowners who are directly interested. It is believed by good attorneys that this model law will be found adequate and clear in methods of organization, administration, and maintenance of reclamation districts. There are over two dozen drainage districts already organized under this law; in several of these the work has been carried to successful completion, and thus far the law has proved thoroughly practical. Drainage districts organized under similar district laws have effected a wonderful transformation in much of the Corn Belt. District drainage will make it possible to double the productiveness of much of the 70,000,000 acres of wet land in the United States. As explained later, Oregon has recently

provided for state guarantee of interest payments for the first five years on approved feasible projects.

Where a few persons agree to drain coöperatively, they may petition the county court and undertake drainage on their own responsibility. Oregon also has a state diking district law which has proved to be simple and practical for small projects. Wisconsin has a township ditch law which is said to be simple and practical for small community drainage enterprises.

Where two adjoining owners are concerned in a drainage system, a common arrangement is for the upper landowner to pay for the difference in size of tiling across the lower owner's land so as to secure underground outlet capacity for his land. In Oregon, right of way can be secured by arbitration, and assessments of benefits and damages, or by condemnation if arbitration fails.

Drainage District Procedure

The Tillamook Drainage District. — The Tillamook district was the first to be organized under the Oregon law of 1915, and, since it has been carried to completion, this district project is used herein as an example. At the request of persons interested, through their county agriculturist, the major author, accompanied by an engineer of the United States Office of Drainage Investigations, made a preliminary examination of the district, May 15, 1915. The tract a mile or so wide and a mile and a half long, shown in Figure 51, is located just south of the city of Tillamook, Oregon, and includes a marshy area too wet to afford much pasture. The soil below the tenth contour is peaty muck underlain with blue clay at 5 or 6 feet. Silt loam covers the remainder of the bottom land, while a gravelly loam extends over the bench. The rainfall is perhaps 75 inches a year. Preliminary levels and soil examinations were made to determine the feasibility of the drainage, and a canvass was carried out to determine the sentiment of owners in regard to the organization of the district. Very little opposition was encountered; and, as the

soil and topographic conditions were favorable, a petition for organization of a drainage district was prepared.

Organization. — The prepared petition and notice of hearing are presented herewith, to give a definite idea of procedure

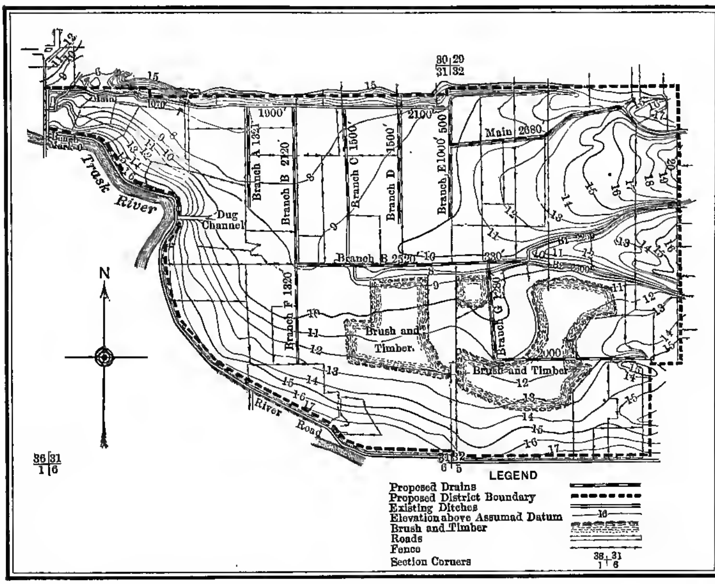

FIG. 52. Map of Tillamook drainage district, Tillamook County, Oregon.

under the new law. The petition is required to be published as a part of the notice.

"NOTICE OF HEARING PETITION TO FORM DRAINAGE DISTRICT"

IN THE COUNTY COURT OF THE STATE OF OREGON, FOR THE COUNTY OF TILLAMOOK

Notice is hereby given that hearing on the following petition will be held at the Court House in the City of Tillamook, County of Tillamook, State of Oregon, on the 16th day of July, 1915, for the purpose of determining whether the prayer of said petition shall be granted.

All persons owning or claiming an interest in lands described in said petition are hereby notified to appear at said place and on said date if prayer in said petition should not be granted.

(*Signed*)

Clerk of County Court.

PETITION

To the Honorable County Court of Tillamook County, State of Oregon.

The undersigned, being owners of more than fifty per cent of the acreage of the contiguous body of swamp, wet, and overflow land in Tillamook County, Oregon, hereinafter described, do hereby petition your Honorable Body to cause to be organized a drainage district for the purpose of having such lands reclaimed and protected from the effects of water, for sanitary and agricultural purposes and for the convenience and welfare of the public, utility, and benefit; and for the purpose of this petition we state the following matters as required by Chapter 340 of the General Laws of Oregon, for the year 1915:

I. The name proposed for such district is " Tillamook Drainage District."

II. The boundary lines of the proposed district are as follows:

(*Here followed description of boundaries by legal subdivisions.*)

III. The total acreage included in the said proposed district is 555 acres.

IV. The names of the owners of the land in said proposed district, as shown by the records of Tillamook County, Oregon, and the acreage owned by each of said owners is as follows:

(*Here followed names of twenty-two owners concerned, and acreage owned by each.*)

V. The proposed reclamation and protection of said lands is for sanitary and agricultural purposes; and such proposed reclamation and protection will be conducive to the public health and welfare, and of public utility and benefit.

VI. All of the lands included in said proposed district are

properly included therein, and will be beneficially affected by the operations of the proposed district.

VII. The benefits of such proposed reclamation and protection will exceed the damage to be done; and the best interest of the land included, and of the owners of such land as a whole, and of the public at large, will be promoted by the formation and proposed operation of said district.

VIII. The formation of a drainage district under the provisions of Chapter 340 of the General Laws of Oregon for 1915, under the provisions of which this petition is proposed, is a proper and advantageous method of accomplishing the reclamation and protection of the land in said proposed drainage district.

IX. The proposed plan for the reclamation and protection of the property in the proposed district is, that a ditch shall be put in, running from the west side of the proposed district (connecting with a ditch running along the west side of the district which empties into the Trask River,) easterly along the foot of the hill which is along the north side of the district, following the line of the ditch already partially constructed in that locality to the east side of the district. Also there is to be constructed another ditch connecting with the ditch above mentioned, running south on the west line of the east half of the northwest quarter of the Section 31, in Township 1 South, Range 9 West to the quarter section line running east and west through said Section and running thence east along the quarter section line to the east line of the proposed district or so far as may be found necessary for the drainage purposes in this section. The two ditches are to be the main ditches for the drainage proposed, and they are to be constructed with such laterals as may be found necessary to make the drainage effectual. The land included in the proposed district is so situated that, without ditches being constructed, the water is not drained off, and the land remains cold and sour. There is a fall of about 25 feet from the east side of the district to the west side thereof, and it is believed that with the construction

of the ditch as proposed the water will be drained off from all of the lands so that they will dry much more rapidly, and the same will be in proper condition for cultivation, and much more productive.

X. The signers of this petition agree that they will pay any and all expenses incurred, and any tax or taxes that may be levied against their respective lands for the purpose of paying the expense of organizing or attempting to organize the proposed district, such expense to be taxed against the lands of the signers in proportion to the number of acres owned by them and affected by the proposed drainage.

XI. Wherefore, your petitioners pray that the lands described herein, or such of them as may be found by the court to be properly included in the proposed drainage district, either permanently or until further investigation and surveys may permit elimination, shall be declared organized into a drainage district under the provision of Chapter 340 of the General Laws of Oregon for the year 1915.

Dated this May 28th, 1915

(*Here followed signatures of owners*)

STATE OF OREGON }
COUNTY OF TILLIMOOK } *ss*

I, ______________________, being first duly sworn, say that I have read the foregoing petition and that I believe the allegations thereof to be true. I further state that the signatures appended to said petition are true and proper signatures of persons whose names appear signed thereto, and that each and all of said signers of said petition are owners of the land within the proposed drainage district as set forth in said petition.

Notary

Subscribed and sworn to before me this 2nd day of June, 1915.

County Clerk

First publication June 3rd, 1915.
Last publication July 1, 1915.

In June, the Government Engineer returned and made the field survey, with assistance furnished by the district, and prepared the plan of reclamation indicated on the accompanying map of the district. Poor drainage and the shallow water-table were due to lack of outlet. The present purpose of the new drains is to remove the flood-water quickly in the spring, and supply outlets to the individual tracts. The main ditch and the several laterals were laid out with a mean depth of about 6 feet. Construction work was completed the same season, and the crop increase the following year was worth more than the entire drainage cost.

QUESTIONS

1. What is the purpose of a drainage district law?
2. Upon what principle is a drainage district law based?
3. What portion of the acreage must be signed up before filing any drainage district petition in Oregon?
4. What things must this petition contain under the model district law?
5. How are the drainage district officers selected, and what are their duties?
6. Who appoints commissioners to assess benefits and damages, and what qualifications must these assessors possess?
7. What are the chief differences in the district drainage laws of different states?
8. Give an example of the method of procedure and results under district drainage.

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CHAPTER XIV

ASSESSMENT OF DRAINAGE BENEFITS AND COSTS

It is of fundamental importance in a drainage district that the assessment be in proportion to the benefits, so that each may pay only for the drainage he gets. The benefits may be classed as special and agricultural. Special benefits include benefits to highways, railways, power lines, town lots, or outlets to factories. Agricultural benefits are increases in value of land, due to greater productiveness, accessibility, and decreased cost of agricultural operations. Increase in productive and speculative values should both be considered. Construction and operation of an outlet ditch helps to consolidate and develop the community through general improvement in accessibility and healthfulness. Damages are assessed separately and allowance made therefor. Laws of most states stipulate that the benefits must exceed organization and construction costs, plus damages, in order to be of community benefit and secure court approval.

Assessment of Damages. — The commissioners appointed to appraise benefits may in some states assess damages; but these are usually carried separately, the two not being allowed to offset each other. In allowing damages for an open ditch-way across a field, the additional ditch-way needed may be actually bought. Sometimes a bridge is built for the owner or its cost allowed and the owner authorized to build it. Building the ditch may spoil a watering place for stock, and damages may be allowed to the amount of a well and pump, or a creep may be authorized and its cost allowed for. Damages are sometimes claimed by owners farther down the creek; but in dozens of cases the results show that floods are lower after drainage, because the drained area constitutes a reservoir of

dry soil which absorbs the rain and equalizes the runoff. Small parcels of land cut off by the ditch so as to be of little use are paid for by the district.

Highways are allowed damages where district ditch crossings are constructed with road funds. Railways may be allowed damages equal to the difference in the value of old bridges and new ones required for the outlet ditch crossings.

Special Benefits. — Special benefits from drainage are assessed against railroads, highways, power lines, town lots, and factories. Where a highway is benefited, a share of the drainage tax should be assessed against the road funds. The same is true as to railroads where drainage lessens floods and decreases the maintenance cost. If before drainage the track was occasionally flooded, and drainage lowers the high-water mark to 3 feet below the rails, then the benefit can be estimated on the basis of the amount of fill that would have been required to accomplish this. The drainage tax may amount to one-third the benefits. City lots may receive special benefits, which may run as high for a lot as for an acre of agricultural land. Creameries may agree to pay certain amounts for sewage outlet privileges.

Principles Underlying Assessment of Benefits. — Laws of most humid states stipulate that assessment of costs shall be in proportion to benefits. This theory is based on the consent of the majority of owners to pay for what drainage they get. Assessments for drainage in irrigated lands of arid sections are often made on a flat rate per acre. This theory is based on the idea that the owners of higher-lying lands or irrigation canals are responsible for water they divert from the natural water courses and should help take care of their seepage or waste. Such assessments are levied as a police duty of the municipality. The supreme court of Oregon and the state legislature have upheld the idea of assessing contributing damages or charges against such higher-lying property. Proponents of this theory argue that it is impossible to predict when the lands located in higher parts of a project may come to need drainage as the irrigated area is extended.

Laws of most states provide for assessments according to benefits. This seems to be the broader principle, as it permits use of a flat rate where all the land is similarly benefited, as within a meandered marsh. However, in applying to an arid country, a law devised for a humid one, we are apt to find it a misfit, and *vice versa.*

The following considerations should be kept in mind in assessing benefits and costs under the humid drainage laws.

(1) The owner is entitled to the natural drainage his land possesses; but if the district system cuts off water from land above him, the benefit of this intercepting drainage should be assessed according to the improvement it makes in the condition of his land. This would apply also to an owner on whose land the natural outlet for the district is located.

(2) Topography is a leading consideration, for the purpose of the district is to provide outlets for field drains where the fields have been too flat for tiling out at a good depth.

(3) The distance from the natural outlet is a factor, as the drainage ditch provides for the distant land the benefits which the land close to the outlet already in a measure had.

(4) Assessments are less where only partial drainage is provided, as in the case of land located farther back from the drainage ditch or near the shallowest portion of the ditch.

(5) Land of high fertility and good drainage properties should be assessed more than that of lower quality because the value of the drainage is greater.

(6) Crop adaption and climatic conditions should be considered in estimating benefits.

Methods of Assessing Benefits. — Commissioners should walk over every 40-acre tract, accompanied by the project engineer, and classify lands with great care. The commissioners usually choose their own scheme for levying assessments. On marsh or arid land, the agricultural taxes may be on a flat

rate. Where assessment of benefits is required in apportioning costs the land is usually classified, and a value estimated for the area of each tract belonging to each class before and after drainage. It is sometimes assumed that the drainage is a public benefit and the main consideration is given to existing value of property as in other property taxes. Sometimes classes of benefits are established for different areas and in other cases lands are classified and assessed according to percentage of benefit.

In classifying land for drainage taxes, probably the simplest method is dividing the land into classes and then rating the very wet or marsh acres at 100 drainage points an acre. The wet agricultural land will be rated at a lower number of points an acre, and only a few points an acre will be levied against land already tillable. The number of acres in each class is then multiplied by the number of drainage points assessed against it, to get the total number of units of agricultural tax. After deduction of special assessments from the total estimated cost, the balance is divided by the total number of units as obtained above, to get the tax per unit. The assessment list of the Tillamook Drainage District is again referred to for an illustration of this method of assessment.

TABLE XVIII. — ASSESSMENT LIST OF THE TILLAMOOK DRAINAGE DISTRICT, STATING THE BENEFITS AND DAMAGES

Owner	Acres Assessed	Points of Drainage Assessed per Acre		Total Points of Drainage	Total Acres
No.					
1	10.33	100	1033		
1	28.33	5	141.65		
1	21	9	189		
1	40.34	100	4034	5397.65	106.63
2	100	100		10000.	110
3	62	100		6200	80
4	22	100		2200	27.51
5	10	100		1000	12
6	5	100		500	6.28
7	5	100		500	5.
8	2.5	100		250	2.5
9	8	100	800		
9	6	100	600		
9	13.51	50	675.5	2075.5	27.51
10	8.5	67		569.5	33.58
11	9	52		468	46.28
12	9	52		468	37.52
13	12	52		624	30
14	34	100		3400	40
15	5	90		450	44
16	60	100		6000	76
17	12	100		1200	14
				41302.65	698.81

Benefits of old ditch which was appropriated by the Tillamook Drainage District, to be refunded as follows by the Tillamook Drainage District.

No. 1	$160.00
" 2	140.50
" 4	25.00
" 16	25.00
" 3	113.00
	$463.50

————*Clerk*
————*Commissioner*
————*Commissioner*
————*Commissioner*

Subscribed and sworn to before me this 13th day of Dec., 1915

————*County Clerk*

Where the law requires benefits to be fixed, the following form is suitable.

TABLE XIX. — ASSESSMENT OF TAXES ACCORDING TO BENEFITS

Parcel	Acres		Apportionment of Cost Dollars					Addition and Subtraction			
No.	Benefited	Not Benefited	Main Ditch	Lateral	Small Tile	Oregon Irrigation	Total	Reason	Amount	Tax Benefits	
1	40	0	400	0	2000	80	2480	.....	+80	2560	5120
2	40	0	400	0	0	80	480	Deep Peat	−80	400	800
3	40	0	200	240	2000	80	2520	.....	+80	2600	5200
4	40	0	160	240	0	80	480	Heavy Clearing	−100	380	760
5	40	0	0	240	2000	80	2320	.....	+80	2400	4800
6	40	0	400	0	0	80	480	Ditch dug 4 feet deep	−200	280	560
7	15	5	160	1000	0	30	1190	.....	+30	1220	2420

The above form, suggested by E. R. Jones, is convenient for making assessments where the law requires benefit to be fixed in arriving at drainage district taxes.

In the Tillamook district there were 698.81 acres, and each acre was assessed the number of drainage points corresponding to the amount of benefit. The total of drainage points as shown by the assessment list for the district was 41,302. These were assessed five cents a point, raising $20,065.13. The total cost of securing the outlet drain amounted to $1612.57, leaving a balance of $452.56 to be used for maintenance.

Distribution of Costs. — The various items of expense were as follows:

Attorney fees for drafting petition	$50.00
Engineer and helpers	38.19
Advertising	50.00
Excavating new ditch and repairing old ditch	990.88
Old ditch used by drainage district	463.50
Three commissioners, one day	15.00
Clerk, one day	5.00
Total	$1612.57

The construction work was carried to successful completion in the summer and fall of 1915.

Results. — The secretary of the Tillamook Drainage District writes that they have found the new law adequate and practical, while the increased yields have returned at least half the total cost of the district during the first year. As the cost was only about $3 an acre, the expense was handled on a cash basis without issuing bonds. Since the outlets have been provided, several owners in the district have completed their field drainage by supplementary underdrains.

Drainage District Bonds. — The model district drainage law provides that bonds may be issued to distribute the expense of providing outlet ditches over a period of twenty years, during which time the increase in yield from drainage should be abundant to provide profits for retiring the bonds. The distribution of bond payments is shown for a $6 annual tax table.

TABLE XX. — ANNUAL PAYMENTS ON A 6 PER CENT FIVE TO TWENTY YEAR DRAINAGE BOND, WHEN ASSESSED AT $6.00 FOR THE ACRE

Years	Prin. Maturities	Interest	Prin.	Total Annual Payment
1		.36		.36
2		.36		.36
3		.36		.36
4		.36		.36
5		.36	.40	.76
6	.40	.336	.40	.736
7	.40	.312	.40	.712
8	.40	.288	.40	.688
9	.40	.264	.40	.664
10	.40	.240	.40	.640
11	.40	.216	.40	.616
12	.40	.192	.40	.592
13	.40	.168	.40	.568
14	.40	.144	.40	.544
15	.40	.120	.40	.520
16	.40	.096	.40	.496
17	.40	.072	.40	.472
18	.40	.048	.40	.448
19	.40	.024	.40	.424
20	.40			
	$6.00	$4.311	$6.00	$10.311

When assessed at $12 an acre, the above figures would be doubled.

This allows five years to get the newly drained land into going condition before principal payments begin. The maximum annual payment on an acre assessed at $6 would be 76 cents. This would represent increased crop value equivalent to about 2 pounds of butter fat or ½ bushel of wheat at current prices.

Several districts organized in Oregon have issued bonds and have found a ready sale for them. Good bond attorneys state that the law provides for a good bond. In the central states, drainage district bonds are regarded as good investments and, in places, sell above par. It is said to be important that the law be carefully followed if this is to be the case. Drain-

age district bonds are said to be most attractive where the land in the district is owned by those who live on the land and develop it, rather than where land is held for colonization purposes under corporate ownership. Usually the total amount of bonds is small in proportion to the aggregate appraised value of land in a drainage district; but it is well to get practical assurance that the benefits will exceed the total cost of drainage. The total indebtedness of the district for all purposes, including drainage, should not be allowed to become burdensome. The short community ditches in many sections can be paid for on a cash basis without bonds, if a rural credits measure or the federal farm loan act provides money at moderate interest rates.

State Guarantee of Drainage Bond Interest. — A measure recently enacted in Oregon provides for state guarantee of interest for the first five years on bonds of feasible, approved drainage districts. The law requires that the project must be carefully investigated at the expense of the district, and must be found feasible in several particulars and "for the best interests of the district and the State" before the project can receive certification. Certification is placed in the hands of a commission composed of the Attorney General, State Superintendent of Banks, and State Engineer. The bill gives preferential entry right to persons who have been engaged in military service. It is believed that the state guarantee will help project bonds to sell promptly at a higher rate and with less selling expense. In case the state advances any interest it is to be returned later when the project is in a going condition. In localities where there are a number of drainage problems to be met, the state or Federal experiment stations make a practice of sending a field man to make examinations and to give a demonstration or advise the community as to the means of securing drainage. Field work usually consists of subsoil and water-table examinations and the taking of some preliminary levels, to determine the available fall or best possible outlet and the location and design of drains required. Where there are several days of surveying to be done, it will usually be

necessary to secure services of a professional engineer. This preliminary work aims only to aid drainage enterprises in getting started right without having to compete with private enterprise. Arrangement can often be made with the United States Office of Drainage Investigations to coöperate in securing some preliminary data in sections where the practice of drainage is entirely new. These investigations aim to determine the feasibility of the proposed drainage project from an engineering and agricultural standpoint. The result of such preliminary investigation will be the organization and development of feasible projects. To carry these projects through, a good attorney and a drainage engineer should be employed; it will pay to have the work done right. The states could well afford to carry on more extensive investigations of the effect of underdrains in the marshy, alkaline, wet clay, and other wet lands.

QUESTIONS

1. What different classes of drainage benefits are recognized?
2. Under what conditions are damages allowed?
3. How are special benefits to roadways estimated?
4. State the arguments for assessment on a flat rate in arid sections.
5. Upon what principles are assessments of benefits based?
6. Outline one method of classifying land and calculating drainage taxes.
7. What are the main items of cost in a drainage district?
8. What are the terms of the usual drainage bonds?
9. How is the rate of repayment graduated on a 6 per cent five to twenty year bond?
10. What factors would help determine the value of a drainage bond issue?
11. How is interest on drainage bonds guaranteed in Oregon?
12. What advantages are claimed for State Guarantee of bond interest during the first five years?
13. How do state and Federal experiment stations aid in drainage development?
14. How does the States Relations Service assist in drainage?

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CHAPTER XV

LARGE TILES vs. OPEN DITCHES

THE best tile system ever laid would be a failure without an outlet. Every tile-line must have an outlet, whether it be into an open ditch or into another larger tile-line.

Nature's Outlet. — The natural outlet is the open ditch; but, unfortunately, Nature has left many of her outlets in bad shape. She leaves them in the form of winding rivers, often 150 feet wide and very shallow, with a fall of perhaps a foot to the mile, often even less. When the channel is deepened and straightened this may be sufficient. The unfortunate thing about the straight, narrow, deep ditch is that it is not natural, and Nature at once undertakes to undo the work of man, making the ditch winding and sinuous; and in a few months or years, at most, man has his work to do over again.

FIG. 53. The Grande Ronde River, Oregon, showing oxbow meanderings.

Large Tiles vs. the Open Ditch. — For the large winding stream the straight, open ditch is, of course, the only satisfactory substitute; but for the narrow, sluggish, winding stream whose surface is but little below the surface of the

ground, the covered tile-drain may be substituted. The smooth, straight walls of the tile-drain offer much less friction to the flow of water than the rough, irregular sides and bottoms of open ditches; therefore, a tile-opening much smaller than the ditch-opening will carry an equal amount of water. It is thus apparent that for smaller streams the covered drain of big tile is much to be preferred, especially where the original open drain or creek-bed is dry for a large part of the year. There are cases, however, between the extremes of the large river and the small open ditch where local conditions must determine which is the better outlet, an open ditch or big, covered tiling. Sometimes a broad surface run for flood-water may be used in combination with tiling of moderate capacity. Open drains are unsightly. They harbor noxious weeds and underbrush. They occupy valuable land and increase the difficulties of cultivation by cutting the remaining land into irregular shapes. They necessitate the construction of bridges and culverts. They require more or less cleaning each year. Although with open ditches there is no tiling to buy, and the original cost may therefore be less, it must be remembered that consideration of first cost alone has caused many a man to lose a fortune.

Fig. 54. Outlet bulkhead and protection. (Photograph Barr & Cunningham.)

The chief difference between the open ditch and the covered tile-drain is that when the tile-drain is properly finished and covered, expense, except for interest on money invested, is very moderate. The life of the tile-drain is generally unlimited. With the open ditch, on the other hand, first cost is only the beginning. Each year the interest on the investment must be

met; in addition there are maintenance charges for cleaning and clearing and repair of fences; and there is the annual loss due to failure to grow a crop on the ditch right of way.

The open ditch must always be dug deep enough to furnish an outlet for lateral drains. It must be at least 6 feet deep, while the bottom width must be sufficient to allow a team and scraper to work, or about 4 feet. The side slopes cannot be steeper than 1 foot horizontal to 1 foot vertical. Thus all ditches below a certain capacity must be made of one size in order to facilitate working with the construction machinery. Cases may therefore occur in which an open ditch is more expensive than the covered drain.

Fig. 55. Outlet ditch of Malheur Drainage District. (Photograph Barr & Cunningham).

To illustrate: A certain outlet drain is to carry 8 cubic feet of drainage-water per second. A question arises as to whether it is better to build an open ditch or a covered concrete drain-pipe. The slope is 5 feet to the mile. The ditch must have the following dimensions:

Depth	6 feet
Width at bottom	4 feet
Side slopes	1 to 1
Yardage per rod	37 yards
Cost of excavation at $0.13½ a yard ($0.13½ × 37)	$5.00
Fence on both sides per rod	1.00
2 rods Rt. of way at $0.50 sq. rd	1.00
1–8 ft. Bridge every quarter mile, tile inlets, etc.	1.00
Leveling banks	1.00
$0.20 Maintenance per Cap. at 5 per cent	4.00
	$13.00

Now, 24-inch concrete tiling will carry this water on this slope, and the cost will be as follows:

24-inch tiling at $0.60 a ft.	$9.90
Trenching, laying, backfilling	4.00
	$13.90

There being no right of way, fences, maintenance charges, or bridges, it is clear that in this case concrete tiling is the cheaper.

Professor E. R. Jones of the University of Wisconsin says, "I believe that an open ditch 6 feet deep, 4 feet wide at the bottom and 16 feet wide at the top, is the smallest open ditch that has a right to exist as an outlet drain."

Where there are 4 or 5 miles of such ditching, the excavating can be done for $5 a rod. But to this must be added at least $5 more for right of way, maintenance, bridges, fences, leveling banks, etc., making a total of $10 a rod. But $10 a rod will lay an 18-inch covered drain, complete; and the trouble about maintenance is forever out of the way; besides, there are no bridges, no fences, no steep banks, and the land may be cultivated over the drain.

Tiling 5 feet deep is better than a ditch 6 feet deep, because there are few ditches that will not silt up to the depth of a foot, even with the very best care.

Dredges cannot dig ditches narrower than 4 feet on the bottom and 16 feet on top. If a ditch of these dimensions is wide enough at the outlet, it is too wide at the upper end. With tiling, on the other hand, a drain which is 18 inches at the outlet can be gradually decreased to 6 inches at the upper or head end.

Advantages of Large Tiling. — Large tiling well laid does away with many difficulties.

(1) There are no ditch-bottoms bulging upward from the weight of the soil-bank on the side.

(2) There is no slush settling into the bottom to cause trouble for years to come.

(3) There are no caving sides where 10 or 15 wagon loads of dirt fall at a time into the ditch-bottom to stop the drainage.

(4) There are no damages to the property which is crossed by a covered tile-drain.

(5) Covered outlet drains are usually accompanied by a liberal system of covered laterals, which drain the surrounding soil to such an extent that it acts as a reservoir for flood-water in the flood season, thus giving the tiling several days in which to carry off the flood-water; whereas when only open ditches are used, the flood-water rushes off in a few hours, requiring much larger outlet capacity.

(6) In irrigated country, open drain ditches give trouble from excessive growth of vegetation in the drain. If covered drains are used, the principal troubles encountered are from the roots of trees, quicksand, and "blow-outs." Trouble from tree roots can be avoided by cutting away the trees in the immediate vicinity of the drain. Quicksand can be kept out by filling the trench with gravel both below and above the tile.

Practise in the humid sections tends more toward the use of the covered drain. Tiling having a diameter of 3 feet is not uncommon, and larger sizes are sometimes employed. Conservative estimates made by the United States Department of Agriculture show that it is generally more economical to use 20-inch tiles than an open ditch of the same capacity.

QUESTIONS

1. Why is the velocity less in a winding river than in an open drainage ditch?
2. How does the straightening and deepening of the river channel increase its capacity to carry water?
3. Why do farmers object to building an open ditch through their farms?
4. How does the covered drain meet this objection?
5. Name five points in favor of the covered drain, rather than the open ditch, for an outlet.
6. What items must be considered in calculating the total cost of an open ditch?
7. How many and which of these items drop out in case of the covered drain?

8. At what size of tiling does it become more economical to substitute the open ditch?

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CHAPTER XVI

DESIGN, CONSTRUCTION AND MAINTENANCE OF OPEN DITCHES

EVERY line of tiling must have an outlet. The best system ever constructed would be a failure if the outlet were insufficient. Some systems consist of single lines of tiling, each having an independent outlet into an open ditch. It is an improvement on this plan to have the lines of smaller tiling discharge into a line of common larger tiling, and this in turn into the open ditch through a single inlet. But there must be an outlet system, whether it be tiling, a natural river a ravine, or an open ditch. The outlet system may also be an artificial combination of all of these.

FIG. 56. A bypass for drain from Devil's Slough under Hennipin Canal in Illinois.

Nature has left most of her outlets in bad shape, so that a great amount of design and construction work is necessary in the utilization even of natural outlets. In case of the use of sluggish winding streams as outlets, cleaning, deepening and straightening the natural channel will usually give sufficient capacity to the stream to make it serve properly as an outlet. It sometimes occurs, however, that the old stream-bed is so littered with fallen trees, growing timber, underbrush and log-jams that it is really more economical to dig an entirely new channel some distance away, to avoid the expense of clearing. Again there may be no natural

outlet channel at all, in which case an entirely new outlet channel is necessary.

Location of Open Ditches. — The location of the open ditch should follow the general course of natural drainage as nearly as possible, with due regard to alignment. In the location of the outlet ditches, careful consideration should be given to the size and slope of the entire drainage area, so that the completed plan, when carried out, will be efficient and economical. No fixed rules can be laid down for location; but, in each case, a careful study of local conditions is essential. In the location of open ditches, the following general points and the conflicting arguments arising from them should be kept in mind:

FIG. 57. Drainage outlet canal from Devil's Slough drainage district, Illinois. Represents a canal in good condition.

√ (1) The value to stream flow of straight courses and gradual curves;
(2) The desirability of locating drains along property lines wherever possible;
(3) The damage done to farms by ditches which cut off small inaccessible corners of fields, or extend across them in angling or irregular directions;
(4) The economy of traversing natural depressions; and,
(5) The injurious effect of unstable or caving soils on ditch construction and maintenance.

Before locating an open drain, an engineer should go over the entire route of natural drainage, investigating and comparing possible locations, and lining out tentative channels with lath and poles, later measuring and locating the line more accurately. This inspection will often disclose the possibility

of draining to different outlets or shortening the line by cut-offs, and will necessitate a number of trial locations.

Treatment. — Outlet systems require treatment different from that given lateral canals or small ditches intended to accomplish farm drainage directly. The former must usually follow the natural depressions and water courses, while the latter must be located with strict regard to the source of the drainage-water, as is the case with tile-drains. Wherever practicable, small open lateral ditches should extend along the highways, as the roadway is thus drained and less right of way will be required. Furthermore, the waste banks can be thrown into the roadway and crowned, making an excellent thoroughfare where roads would ordinarily be impassable during the wet seasons.

Alignment and Curvature. — All ditches should be as straight as possible, and at the same time conform to the local topography. Short, sharp turns in the channel cause the moving water to come violently into contact with the bank, causing erosion, undermining and subsequent caving of the banks. Caving greatly reduces the capacity of the canal. The sharpness of the curves should depend on the size of the stream, the stability of the earth, and the velocity of the water; but the straighter the ditch, the cheaper its maintenance will be.

The proper curvature to give ditches when they are deflected from a straight line is a matter that requires careful attention. The adjustment of curvature to velocity of flow should be such that the banks will not require artificial protection. The relation of bank erosion to curvature of the ditch and velocity of flow is intricate, owing to the variation in stability of different kinds of earth when subjected to action of flowing water. How short a curve may be used in large ditches such as are constructed for drainage districts, without causing the banks to cave or wash, cannot be stated with mathematical exactness. However it is necessary to set certain limits for the curvature or "degree of curve" in good drainage practice. The "degree of curve" means the angle enclosed at the center of the circle by a 100-foot length of curve. This is an engineer's arbitrary

and convenient method of defining the radius of the curve. For example, a 1 degree curve has a radius of 5730 feet, a 2 degree curve has a radius of 5730 ÷ 2 or 2865 feet, while a 10 degree curve has a radius of 5730 ÷ 10 or 573 feet. Elliott gives the following general specifications for curvature:

For ditches with minimum bottom width of 6 feet and maximum grade of 2 feet to the mile, use 20 degree curve (radius 288 feet).

For ditches with a bottom width of 6 feet and grade of 3 to 6 feet to the mile, use 12 degree curve (radius 478 feet).

For larger ditches and greater fall, or for ditches with the dimensions given but with greater fall than that indicated, 6 to 12 degree curves are used, according to the particular conditions.

Grades. — Nature, to a large extent, fixes the fall or grade of a ditch. Natural channels are, in general, longer than artificial channels, owing to the unnecessary curves in the former. It therefore often happens that nature does not provide enough fall for the natural channel. When artificially straightened, the channel may be so shortened as to cause an excessive grade. It is always necessary to make the artificial ditch conform in grade and cross-section to the fall provided by nature.

But to decide what will constitute a satisfactory grade involves a consideration not only of the requirements of the ditch, but also of the nature of the earth. The grade should be as uniform as practicable. It may vary from 6 inches to the mile to 5 feet to the mile, where gravity ditches are used, or may be less than 3 inches to the mile, when pumps are used. Ditches in some soils with grades above 3 feet to the mile are more difficult to keep in repair on account of the erosion caused by the rapid flow of water. In dense clay soils comparatively steep grades are permissible.

In flat country, all the fall available should be used in the design of the ditch, to make the ditch as nearly self-cleaning as possible. In heavy soils ditches with a fall of 4 feet to the mile may be considered self-cleaning, and larger ditches will clean themselves on flatter grades. When flat grades are used

with small ditches, an increased maintenance cost must be expected, because there will be a tendency for the ditch to silt up. For this reason such flat grades as 6 inches to the mile, although often satisfactory, cannot be recommended.

Shape of Ditch Cross-Section. — The resistance which any channel offers to the flow of water depends on three factors:

(1) the slope of the ditch (which governs the velocity of the water);

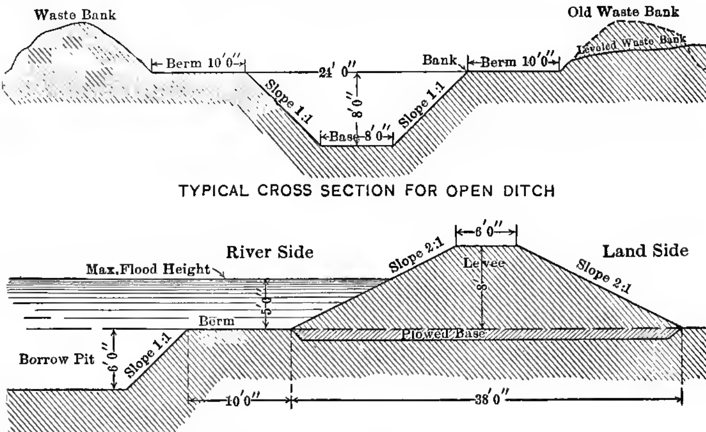
(2) the roughness of the surface with which the water comes into contact; and

(3) the ratio of the area of the water cross-section to the length of " wetted perimeter," which is the bottom and side bounding line of the water cross-section. It is measured from the water-surface on one bank, down the bank to the bottom, across the bottom to the other bank, up the bank to the water-surface again, but not across the water-surface. Nature determines the first two factors, but the designer controls the third to a large extent. The greater the value of this ratio (area ÷ wetted perimeter), the more water will flow in the ditch. Since the ratio, within practical limits of ditch construction, is greater for narrow, deep ditches than for wide, shallow ditches, the narrow, deep ditch is more desirable.

Channels having vertical sides offer less resistance to flow than any other form. Where the fall is slight, therefore, and it is desirable to get the greatest ditch capacity with the least excavation, the ditch should be made deep and as nearly a rectangle or half square as possible. But earth will not stand vertically without a retaining wall; therefore absolutely rectangular ditches are impractical.

Side Slopes. — The rate of side slopes for open ditches depend on stability of the soil, though the method of excavation should be given some consideration. The angle at which the banks will stand depends on the fluidity of the soil when mixed with water; and, unless this angle is maintained, caving is certain to result. On the other hand, since the water has a

tendency to widen the bottom and form a U-shaped ditch, it is not wise to make the side slopes too flat, as all excess soil in the lower corners will erode and silt up the ditch at other points. Again, if the slope is too steep, the upper banks will erode into the stream and partly fill the ditch.



TYPICAL CROSS SECTION FOR 8 FT. LEVEE

FIG. 58. Cross section of outlet ditch and levee.

Ordinary "white land" soil will stand with a slope of 1 foot horizontal to 1 vertical, or 45 degrees. Sandy or loose, loamy soils require flatter slopes of about 2 horizontal to 1 vertical, sometimes 3 horizontal to 1 vertical. Some kinds of peat will stand nearly vertical. The action of the water always tends to widen the bottom of the ditch and make the sides more nearly vertical. Side slopes, as ordinarily constructed by dredges, are ½ to 1, or nearly vertical, because a floating dredge cannot conveniently give the final slope to the bank. Contractors frequently, dig the ditch to the required top width and then allow the banks to cave down to the natural slope. This is not desirable, because the final form the ditch will take can never be predicted; the ditch will cave and the unregulated caving will clog it. A machine which will give the banks their final slope is far more desirable than one which can leave nothing but a vertical bank.

Size of Cross-Section. — It is necessary, before construction work can begin, to determine the size of the drainage channel. The two important factors in determining the size are the grade of the channel and the amount of surface runoff. Each of these factors must be carefully considered in determining the necessary capacity. From the necessary capacity and the available grade, the size of ditch can be computed. Good judgment must be exercised in adjusting the size of ditches to different parts of the drainage area, since it is necessary to consider physical conditions of soil and soil-surface in different localities, as well as the effect of unusual local storms.

In determining the size of open ditch necessary to provide drainage for a given area, one must know the rainfall, the runoff, and also whether underdrainage water is to be taken care of. For a maximum rainfall of 2 inches in twenty-four hours, the runoff would probably be $\frac{1}{4}$ of this amount or about $\frac{1}{2}$ inch. This amount holds for areas up to 2500 or 3000 acres. For larger areas the runoff is less, because the water is slower in reaching the ditch.

There are numerous formulas for the velocity of water in open ditches; but probably the simplest is the Kutter Formula:

$$v = C\sqrt{rs}$$
$$q = av$$
$$Q = avt$$

Explanation: v = velocity in feet per second
C = Kutter's coefficient
$r = a/p$
a = area in square feet of cross-section of water in the ditch
p = length of wetted perimeter, *i.e.* the sum of the lengths down the sides as far as wet, and the bottom
s = the slope of the ditch expressed as the ratio of fall to length
q = discharge in cubic feet per second

t = time in seconds during which flow is calculated

Q = total discharge in time t.

An open ditch must be sufficiently large to be reasonably safe against overflow or backing up of water into the laterals. To insure such safety $\frac{1}{4}$ additional depth may be added to the calculated depth. It should be understood that the depth in the above mentioned cases is the depth below desired water-level at flood stage, which may necessarily be several feet below the actual ground surface, in order to provide proper outlet facilities.

The following example will illustrate the method of computing the size of a small open ditch. In computing large ditches the depth is usually determined by depth of lateral drains, hence the bottom width becomes the variable.

A certain small open ditch is to drain 2000 acres. Its bottom width must be 4 feet in order to allow team to work conveniently, bank slopes of 1 to 1, fall 4 feet to the mile. What should be the depth below high-water level in the ditch, to carry the water if 0.75 inches is the maximum amount of water to be carried in twenty-four hours assuming "n" = .025.

Solution :

$$0.75 \text{ inches} = \frac{0.75}{12} \text{ feet}$$

Volume of water from one acre is

$$43560 \times \frac{0.75}{12} = 2722.5 \text{ (cubic feet)}$$

Volume of water from 2000 acres

$$2000 \times 2722.5 \text{ cu. ft.} = 5445000 \text{ cu. ft.}$$

in twenty-four hours.

From this point we must proceed by a "cut and try" method, "guessing" at a depth, then solving the problem with this assumed depth, noting the error and making a new guess until we find a depth which satisfies our formula for Q. Usually not more than two trials are necessary.

Thus:

Assume the depth to be 3 feet

$$p = 4.242 + 4 + 4.242 = 12.484$$

top width is $(4 + 3 + 3)$

$$a = \frac{(4 + 3 + 3) + 4}{2} \times 3 = 21 \text{ sq. ft.}$$

$$r = \frac{21.}{12.84} = 1.64$$

$$s = \frac{4}{5280} = .000758$$

from table VIIA with $n = .025$ and above values of r and s we find by interpolation:

$$C = 63 \text{ approximately}$$

Since $t = 24$ hours $= 86400$ seconds

$$\begin{aligned} Q &= a\,vt \\ &= 21 \times C\sqrt{rs} \times t \\ &= 21 \times 63\sqrt{\frac{21}{12.484} \times \frac{4}{5280}} \times 86400 \\ &= 21 \times 63\sqrt{1.64 \times .000758} \times 86400 \\ &= 1323 \times .0352 \times 86400 \\ &= 4{,}040{,}000 \text{ cubic feet approximately.} \end{aligned}$$

This is slightly under the required capacity. The solution should now be repeated for, say, a depth of 3.6 ft.

Then:

$$p = 5.09 + 4 + 5.09 = 14.18 \text{ ft.}$$

top width is $(4 + 3.6 + 3.6) = 11.2$ ft.

$$a = \frac{(4 + 3.6 + 3.6) + 4}{2} \times 3.6 = 27.2 \text{ sq. ft.}$$

$$r = \frac{27.2}{14.18} = 1.93$$

$$s = \frac{4}{5280} = .000758$$

from table VIIA with $n = .025$ and above values of r and s we find by interpolation:

$$C = 64 \text{ approximately}$$

$$\text{Since } t = 24 \text{ hours} = 86400 \text{ seconds}$$

$$\begin{aligned} Q &= a\,vt = \\ &= 27.2 \times c\sqrt{rs} \times t \\ &= 27.2 \times 64 \times \sqrt{1.93 \times .000758} \times 86{,}400 \\ &= 1740 \times .0382 \times 86400 \\ &= 5{,}740{,}000 \text{ cubic ft.} \end{aligned}$$

which is close enough to the required value. Usually two or three trials are sufficient to get the required result.

Ordinarily this calculation is not resorted to at all. The farmer builds a ditch and watches it for a few years; if it appears inadequate he deepens and widens it. But an engineer, after his surveys are made, must specify a certain size of ditch, in which event he either uses the above method or a set of tables calculated by the above formula, showing the proper size of ditch for various grades and drainage areas.

The following table gives the dimensions of a few typical ditches with side slopes of 1 to 1, which may serve as a guide in the selection of a proper size for the ditch. It is based upon R. B. Buckley's " Design of Channels for Irrigation or Drainage," to which reference may be made.

The column headed " condition of channel " illustrates the great effect of the coefficient of roughness, n, of the channel bed. The n is the value used in Kutter's formula for calculating C in the formula

$$\begin{aligned} v &= C\sqrt{r.\ s.}, \text{ where} \\ v &= \text{velocity;} \\ c &= \text{a variable coefficient;} \\ r &= \frac{a}{p} = \text{area} \div \text{wetted perimeter;} \end{aligned}$$

S = slope of the channel expressed as a decimal fraction. The channels marked " A " are suitable when discharge and depth are fixed and ground will permit slopes indicated. The channels marked " B " are best if discharge only is fixed. Those marked " C " are best when discharge and slope are fixed and the depth may be variable.

TABLE XXI.—TYPICAL CHANNELS. SIDE SLOPES 1 TO 1
(BASED ON KUTTER'S FORMULA)

Base	Depth of water	Water-way	Velocity per sec.	Hydraulic mean depth	Condition of Channel: Very good $n = 0.020$	Good, average $n = 0.025$	Bad $n = 0.030$	Kennedy's "critical velocity," per sec. V_o	
Feet	Feet	Sq. ft.	Feet	Feet	Surface Slope. Unity in:—			Feet	
Channels discharging about 5 cubic feet per second									
40·0	0·5	20·0	0·25	0·48	17,000	12,000	8,500	0·24	A
12·5[1]	0·75[1]	10·0	0·50	0·57	7,000[1]	4,500	3,000	0·54	A
5·0	1·0	6·0	0·85	0·77	4,000	2,600	1,600	0·84	A
1·5	1·5	4·5	1·10	0·8	2,800	1,700	1,100	1·07	B
1·7	2·0	7·5	0·65	1·0	10,000	6,500	4,200	1·30	C
1·8	2·2	9·1	0·55	1·1	15,000	10,000	7,000	1·38	C
2·0	2·4	10·5	0·50	1·2	20,000	14,000	9,000	1·46	C
Channels discharging about 10 cubic feet per second									
26·0	0·75	20·0	0·50	0·71	10,000	7,000	4,400	0·54	A
10·5	1·0	11·5	0·85	0·86	5,000	3,200	2,000	0·84	A
4·5	1·5	9·0	1·10	1·03	4,000	2,600	1,700	1·07	A
2·0	2·0	8·0	1·30	1·05	3,000	1,900	1,300	1·30	B
2·2	2·6	12·5	0·80	1·3	10,000	6,500	4,500	1·54	C
2·3	2·8	14·3	0·70	1·4	15,000	9,000	6,000	1·62	C
2·6	3·0	16·8	0·60	1·5	20,000	14,000	9,500	1·70	C
Channels discharging about 25 cubic feet per second									
29·0	1·0	30·0	0·85	0·94	6,000	3,500	2,200	0·84	A
14·0	1·5	23·3	1·10	1·27	6,000	3,400	2,200	1·07	A
7·5	2·0	19·0	1·30	1·45	4,800	3,000	2,000	1·30	A
4·0	2·5	16·3	1·50	1·47	3,600	2,400	1,550	1·50	A
2·0	3·0	15·0	1·70	1·43	2,800	1,750	1,200	1·70	B
3·0	3·5	22·7	1·10	1·76	10,000	5,500	3,600	1·87	C
3·0	4·0	28·0	0·90	1·95	15,000	9,000	6,000	2·04	C
3·5	4·0	30·0	0·80	2·02	20,000	13,000	9,000	2·04	C
Channels discharging about 50 cubic feet per second									
58·0	1·0	59·0	0·85	0·97	6,000	3,600	2,400	0·84	A
17·0	2·0	38·0	1·30	1·67	6,000	3,600	2,600	1·30	A
11·0	2·5	33·7	1·50	1·86	5,500	3,400	2,200	1·50	A
7·0	3·0	30·0	1·70	1·93	4,400	2,800	1,800	1·70	A
4·0	3·5	26·3	1·90	1·89	3,400	2,200	1,400	1·87	A
2·5	4·0	26·0	2·00	1·88	3,000	1,900	1,300	2·04	B
4·0[2]	4·5[2]	38·3	1·30	2·29	10,000[2]	6,000	4,200	2·19	C
4·0	5·0	45·0	1·10	2·48	15,000	9,000	6,500	2·35	C
4·5	5·0	47·5	1·00	2·55	20,000	12,000	8,000	2·35	C

Example.—[1] A channel with 1 to 1 side slopes to carry 5 cubic feet per second on a slope of 1 in 7000 (n being = 0·020) which will be "non-silting" (on Kennedy's theory) should be 12·5 feet base with 0·75 foot of water.

[2] The "best discharging" channel, with 1 to 1 side slopes (by Neville's construction), to carry 50 cubic feet per second on a slope of 1 in 10,000 (n being = 0·020) should have 4 feet base and 4·5 feet of water; but the channel would silt as the velocity is too small. (P. 163.)

Bottom Widths. — The width of a ditch at its base is of particular importance, since, together with the grade and depth, it controls the capacity. Because of aggravating filling action in ditches serving drainage areas from 1000 to 4000 acres, the base width of main ditches should not be less than 8 feet. This is especially true where floating dredges are used, because they cannot operate in a narrower channel. Contractors securing ditches of narrower base width will excavate the top to a suitable width, in connection with a wider base, thus leaving side slopes too steep. It is therefore better, where dipper-dredges are used, to figure on an adequate base width in the first place and give the ditch the proper design for it.

In ditches for larger drainage areas, the bottom widths are determined by the capacity required.

Small ditches should never have a bottom width of less than 2 feet, else they cannot be easily cleaned with team and scraper. Where the fall is less than 3 feet to the mile, the base width should be at least 3 feet. It is impracticable to make narrower ditches or clean them except by hand labor. Where the fall is 10 feet more to the mile, any form of ditch will be self-cleaning, and protective devices to prevent erosion will often be necessary.

Depths. — The depth must always be sufficient to provide ample outlet facilities for the lowest laterals, with 2 or 3 feet extra depth to provide for the silting up of the main canal which always takes place to that depth during the first few years after construction. The topography of the land through which a ditch passes largely determines the depth it must have. Since greater depths produce greater velocities, a deep channel is more apt to be self-cleaning.

Shallow ditches with wide bottoms are adaptable only for surface runs to carry off the surplus surface-water during flood periods. In order to prove effective as an outlet for a tile-drain, and be reasonably permanent, an open ditch should never be constructed to a depth of less than 6 or 7 feet. This excludes the planning and construction of capstan or cable-plow

ditches, because capstan ditches rarely exceed $2\frac{1}{2}$ feet in depth, and cannot be constructed to grade. Such ditches are expensive and inconvenient, to say the least.

In sand or peat soils, it is more difficult to determine the proper minimum depth. Sand overlain with denser soils, such as are found in Malheur County, Oregon, is apt to run and cause caving of the overlying strata. In cases of such instability, it may be necessary to limit the depth so as to keep above the unstable stratum, or to construct a protective device such as a cunette to hold the sliding banks.

Waste Banks and Berms. — In ditch construction the earth excavated is piled in a ridge parallel to the bank, and at a certain distance from it. This pile of earth is called the waste bank. That part of the natural ground between the ledge of the ditch and the spoil bank is called the " berm."

Waste banks are an inconvenience in the satisfactory cultivation of the adjacent fields. The excavated material, if thrown up by a dredge, is deposited in a wet and plastic condition, and on drying becomes very hard and tough. The waste banks for this reason are very hard to level down and cultivate before the banks have a chance to weather, but for convenience and appearance waste banks should always be partly leveled. Waste banks also act as a levee and prevent water from the adjacent field getting into the ditch. This objectionable feature may be overcome by leaving openings through or under the waste bank at the natural depressions along the ditch. Some engineers will make their waste banks continuous and provide structures for conveying the surface-drainage into the ditch. This prevents silt being carried into the ditch from the banks, and also keeps the banks up in better shape. Concrete, corrugated iron pipes and wooden structures may be used.

A clean berm is essential to all ditches. The purpose of the berm is to keep the weight of the waste bank from causing the bank of the ditch to cave in. The following quotation will illustrate:

" The weight per lineal foot of waste bank for a ditch of 20

feet base, 1 to 1 slopes, and 20 feet in depth, equals 1,481 pounds, wet earth being figured at 100 pounds per cubic foot. As the line of cleavage of the wedges of soil which tend to cave from the sides of any trench is always of curved shape, if the waste banks were deposited outside the surface extremity of this cleavage line, their sliding effect would be entirely prevented."[1]

The proper width of berm depends therefore on the stability of the soil. Since dipper-dredging machines cannot remove the waste farther than necessary to leave a clear berm of 6 to 8 feet, it is better to specify these widths and such side slopes as will insure against caving of the banks when the weight of the waste bank is considered. In case of very large, deep ditches, or in soft marsh, a clean berm of 8 to 12 feet should be specified, depending on the stability of the soil. Wide berms can be secured more easily by the use of machines, preferably of the dry land type with long booms.

The berms should be seeded and sodded to help hold the ditch bank from caving.

Safe Velocity of Flow in Ditches. — Ditches must be made as nearly self-cleaning as possible, but this necessitates increasing the velocity of flow to the limit of safety when the water carries any quantity of silt. The safe velocity is the greatest velocity at which it is possible to let water flow in a ditch without causing erosion or washing of the banks. Kent's "Mechanical Engineers' Pocket Book" gives the following table of safe velocities in various soils:

	foot per second
Pure sand	1.1
Sandy soil 15 per cent clay	1.2
Sandy loam 40 per cent clay	1.8
Loamy soil 65 per cent clay	3.0
Clay loam 85 per cent clay	4.8
Agricultural clay 95 per cent clay	6.2
Clay	7.35

Velocities depend not only on the fall but also on the depth and shape of the ditch, as well as on the roughness of the material of which it is constructed.

[1] Parsons, J. L., Land Drainage, p. 43, 1915.

Character of Drainage Area. — The character of the drainage area affects the rate of runoff and therefore influences the size of the ditch. A broad, flat drainage area will drain more slowly than an area of the same size but with steeper slope. In the latter case there is not only more water to be handled, because there is less time for percolation, but also a shorter time in which to move it than in the former case. This necessitates a much larger ditch in the case of a steeply sloping drainage area.

Broad, flat areas require larger ditches than long, narrow, flat areas, because in the former case the time of concentration of runoff is the same for all points, while in the latter case the concentration period for the lower end has passed long before the flood-water from the upper end comes down.

Amount of Runoff. — The amount of runoff is given as some fraction of an inch depth of water flowing off in twenty-four hours. This is called the "drainage coefficient." A drainage coefficient of $\frac{1}{2}$ inch in twenty-four hours indicates that the ditches must carry off $\frac{1}{2}$ inch of water from the surface of the whole drainage area in twenty-four hours.

A runoff of less than $\frac{1}{2}$ inch in twenty-four hours should never be considered in figuring the capacity of any open ditch. In the eastern states runoffs of 6 inches in twenty-four hours are not uncommon, and with small areas 1 inch an hour is a possible rate. In selecting a drainage coefficient, one must consider (1) the amount of rainfall and temperature, (2) topography, (3) size and shape of watershed, (4) slope of the land, (5) character of the soil, (6) vegetation and cultivation.

Rainfall and Temperature. — Localities having large annual rainfall have correspondingly large twenty-four-hour storm periods. Localities having warm climates generally need fully as much drainage capacity as cold climates, when the rainfalls are equal, for although the evaporation is greater, the violence of single storms is usually also greater in warm climates.

Topography. — Level areas require smaller coefficients than undulating, hilly areas, because they absorb more water, and

the movement of the latter through the soil and over the surface is slower and more uniform.

The Size and Shape. — The ratio of drainage to rainfall is in general smaller for large areas than for small ones, due to the fact that the rainfall is seldom uniform over a large area, and also because the flood portion of the lower area may be drained off before the flood-water of the upper areas can get down to the lower part.

Character and Culture of the Land. — Undulating or rolling territory, with hard surface-like meadows gives a higher runoff than cultivated lands. If hilly lands are terraced or underdrained the coefficient will be less.

Evaporation and Transpiration of Plants. — Careful experiments in France, Russia, and India show that at the end of the growing season the water-table in wooded tracts is from 2 to 12 feet lower than in the open tracts adjoining. Forestry experts estimate that 40 per cent of the summer rainfall is caught by the leaves and again evaporated in wooded districts.

Construction

Hand and Team Work. — For ditches of small depth where the material is dry and the ground firm enough to support a team, team and scraper work can be done very economically, when the amount of earth to be removed does not exceed 30,000 cubic yards. The earth is first plowed and then removed with wheel or slip scrapers.

In the irrigated section, or where the soil is water-logged, team work is in general not feasible because of the miry condition of the soil, and machine work must be resorted to.

Excavating Machines. — Ditches of greater size than 30,000 cubic yards are more economically dug by dredges. The latter are of two types.

1. Floating dredges.
2. Dryland dredges.

The former have their machinery mounted on a barge with the engine in the rear, turntable and digging machinery in front. The excavator consists of a large dipper and boom or

grab-bucket ranging in capacity from ½ to 3 cubic yards, or more. The dipper type works much as the ordinary steam-shovel, except that the dipper is longer and has greater range.

Fig. 59. A dipper dredge with bank spuds.

Floating dredges are adaptable to very wet land, too soft to support heavy machinery.

Dry land excavators are of many types. With them the

Fig. 60. A dredge with a clam-shell bucket dyking the lower Columbia river.

work must begin at the outlet and proceed upward, so as to keep the land drained under the machinery. Nearly all types

have booms and turntables, the essential difference being in the type of bucket, which may be a drag-bucket, resembling a slip-scraper, a clam-shell, or an orange-peel bucket. There is also a templet or elevator and bucket type, as well as a wheel type, both of which give very smooth side slopes.

The floating dipper-dredge is the type of excavating machine most used. Where many stumps are to be encountered, it is by far the most efficient type of machine. In wet land where the ditches have a cross-section of 100 to 1200 square feet, no other type of excavator will equal it for cheapness of operation. It is not adapted to levee construction because of its short reach. These dredges are made in capacities of $\frac{1}{2}$ cubic yard to 4 or 5 cubic yards, but the most common sizes are 1 to 2 cubic yards. They cost from $5000 up, the cost increasing rapidly with the size of bucket. To insure enough water to float it, this type is usually operated downstream. It may, however, be worked upstream by building dams behind it.

The Orange-peel and **Clam-shell Dredges** are adapted to certain types of soil, where the material is soft and caves readily, such as the muck of southern Louisiana. They are not adapted to soil where stumps are encountered. When provided with a long boom they are well adapted to levee construction.

Fig. 61. A small dry land excavating outfit with orange-peel bucket.

The Drag-line Excavator has a bucket which operates like a slip-scraper. It is constantly increasing in favor for drainage work, and is especially adapted for large ditches and levee work, where the ground will support the machine. It is also suitable for ditch cleaning, and ditch banks can be more easily

sloped with this type than with the other bucket or dipper types of dredge.

The Templet Type of Excavator has a single bucket which moves along a guide frame shaped to the desired cross-section

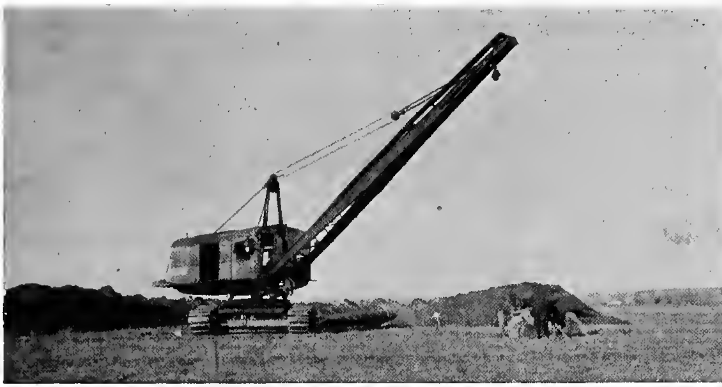


FIG. 62. Drag-line scraper excavator operated by electric power.

of ditch. The whole machine is mounted on caterpillar wheels or a track. It cuts a superior ditch under favorable conditions, but it cannot handle rock, stumps, or very hard earth.

The Wheel Type of Excavator has an excavating wheel which is attached to the rear of the machine and revolves on anti-friction wheels just outside the run of the main wheel. To the outer rim of the large wheel are fastened buckets, which, as the wheel revolves, cut slices of earth from the end of the ditch. With the addition of side knives, the wheel will cut a sloping ditch, the earth from the sides falling into

FIG. 63. Ditch excavated with the drag-line excavator shown in Fig. 62.

the buckets. The ditches cut by this machine, because of their perfect bank slopes, are superior in hydraulic efficiency to those cut by most of the other excavators.

The Hydraulic or Centrifugal Dredge is not suited to open ditch construction. Small types can be used successfully for cleaning old ditches. With the use of slope boards it has been found successful for levee construction.

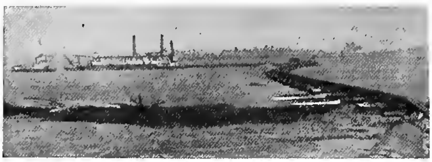


FIG. 64. Hydraulic dredge at work on lower Columbia river.

Maintenance. — A canal, to retain its efficiency, must be well maintained. Twice each year (more often if necessary) vegetation should be removed from the channel and banks, and such material as has fallen into the channel taken out. Any damaged place must be repaired, to prevent further trouble. Tumbleweeds are a source of much annoyance, for they cannot be kept out of drainage canals. They soon form serious obstructions which must be removed at frequent intervals. This is generally done by men equipped with forks and rakes. Cultivation, however, seems to be effective in eliminating the nuisance. Another serious problem is "blow sand," which, during a high wind, may completely obstruct a canal in a few hours. The very nature of a drainage ditch makes maintenance difficult and costly; therefore, every endeavor should be made, during construction, to reduce the amount of maintenance necessary. Since the annual cost of maintaining open canals is often 10 per cent of the first cost, the need for correct design and careful construction is apparent.

FIG. 65. The discharge pipe of the dredge shown in Fig. 64.

Protective Devices for Open Canals. — Checks. — The usual flow in most drainage ditches is not sufficient to cause serious erosion; but occasional floods may increase the flow to such a point that undesirable erosive velocities are attained. In such canals it is advisable to place a check or over-fall dam with a small sluiceway through the lower part. This sluiceway will allow the ordinary flow to pass unchecked, but will check excessive floods, increase the depth of flow, and maintain a safe velocity.

Bridges and Flumes. — Irrigating streams should be carried across drain-ditches in well-built flumes or pipe-lines of a capacity such as to insure their safety and permanence, as much damage may be caused by letting an irrigation ditch into a drainage ditch. When the grades are on the same level, one must be siphoned under the other.

Culverts are not satisfactory in drainage ditches as they are apt to clog and wash out. Good bridges are far more desirable and should be installed at all crossings. A clearance of 2 feet or more is necessary to prevent debris and floating weeds from being caught by the bridge and thus obstructing the channel. No one should be permitted to dam or obstruct a channel in any way.

Ditch Inlets. — There is an established tendency for surface-waters to wash openings in the ditch banks and cut ditches along the water-courses. The silt is carried from these ditches and deposited in the main channel. This can usually be remedied by bringing the surface-water to the canal through a pipe inlet, but even this may have a tendency to wash out, in which case it is necessary to bring it in through a ditch whose grade line connects with the grade line of the main ditch by a gradual incline, so as to prevent erosion. No over-fall into any ditch should be permitted. If flat grades are impossible, drops should be installed. The ditch inlet should be put in place before the ditch is constructed to permit continuous deposit of the waste banks, once construction is begun. Lateral drains should be so located that the water will be discharged in the same direction as that of the flow in the main ditch.

Erosion. — Injury by washing or erosion occurs either by direct wearing of banks and bottom through action of the water which carries the particles downstream, or by action of water on the soft substratum, thus undermining the bank structure and allowing the bank to cave. The erosive action varies as the square of the velocity; that is, if two streams have velocities of 2 and 3 feet to the second respectively, their erosive power will be as 4 to 9. But velocity varies as the square root of the fall. Therefore a stream with 4 feet of fall to the mile will have twice as much erosive power as a stream whose fall is 1 foot to the mile.

Fig. 66. A drainage canal excavated with floating dredge.

Fig. 67. Drainage canal with bank too steep and rough. Grande Ronde Valley, Oregon.

Erosion may be diminished by making the channel wider, thus increasing the wetted perimeter and decreasing the ratio of area of cross-section to wetted perimeter, which has the effect

of increasing the resistance to flow and diminishing the velocity.

Keeping the channel smooth and clean will prevent erosion because it tends to keep the velocity uniform. In large canals, dams and dikes may be constructed to decrease the fall and divert the current from the ditch banks.

Character of Flow. — We have already learned that for a given quantity of water and a specified velocity, the size of the cross-section is determined. Yet it is possible to vary the shape of this cross-section within certain limits. During the dry-weather flow the velocity must be sufficient to keep vegetation from growing in the ditch and silt from collecting on the

FIG. 68. A drainage canal banked with vegetation. Northern Illinois.

bottom, thus eventually filling or stopping the ditch. It is therefore necessary to make the bottom of the ditch narrow, so that the flow will be deeper, will cover the bottom, and will have sufficient velocity to keep down the aquatic plants. In a 10-foot ditch with a fall of 3 feet to the mile, an increase in depth from 2 to 8 feet increases the velocity of flow 45 per cent. Ditches with wide bottoms should not be used except where there is no dry-weather flow. In this case the bottom can be mowed with a mowing machine. The ditch banks should also be mowed twice a year; otherwise weeds and bushes will soon stop up the ditch.

Curvature and Direction of Flow. — The alignment and curvature of ditches greatly influence the maintenance cost.

At sharp curves the current tends to travel in a straight path; therefore it runs into the bank on the outside of the curve. The section of the curve first struck receives the greatest force, and therefore erodes or washes away faster than the rest of the bank. For this reason the upstream end of a curve should be "eased off" or made of longer and longer radius until it becomes a straight line, so that the water will take the bend gradually and not wash into the outer bank.

Uniform Rate of Flow Throughout the Ditch is Essential. — All water carries silt in suspension. Since its carrying capacity varies with the velocity of flow, if the velocity is decreased some of the silt will be dropped and a bar will form, obstructing the channel.

Ditch-Cleaning. — Ditch-cleaning is an expensive form of maintenance. The wet, miry condition of stream-beds makes hand or team and scraper work almost impossible. On the other hand, the amount of material to be removed is so small as to make heavy machinery impracticable because of the great expense of moving the machines. Cleaning old ditches, therefore, may cost as high as $0.50 a cubic yard, where the first cost may have been $0.10 or less. The necessity of designing the ditches in the first place so as to make them self-cleaning cannot be over-emphasized.

FIG. 69. Lateral ditch cleaner operated by a gasoline engine.

Recently, hydraulic or centrifugal dredges of small size, with cutting wheels, have been designed and have proved their usefulness by cleaning old ditches quite economically.

Fencing Ditches. — A Large Open Ditch Should Always be Fenced. — If stock are permitted to graze on the ditch banks, they will, by their continued tramping, cause the ditch banks to cave gradually into the ditch and in time so completely fill it

that its utility as a drainage ditch will be destroyed. This danger can be overcome in one way only; that is by keeping the stock off the ditch bank. All crossings should be bridged, because fording also has a tendency to fill the channel and cause silt to be washed down and deposited in some undesirable place. It is an erroneous impression, though a very popular one, that a ditch, once constructed, is there for all time. Only by careful oversight and protection can a ditch be kept efficient.

QUESTIONS

1. What is the purpose of an open ditch?

2. Tell in detail how to proceed with the calculation to determine whether to use an open ditch or a covered drain.

3. How many acre-feet per twenty-four hours are equivalent to one cubic foot per second? How many acre-inches?

4. On a slope of 5 feet to the mile an outlet drain is to be constructed to drain 500 acres at the rate of $\frac{1}{4}$ inch of runoff each twenty-four hours. Assume that the open ditch must be 6 feet deep, 3 feet wide on the bottom, and side slopes 1 to 1; also that right of way costs $0.50 a square rod; that the ditch can be dug for $0.15 a cubic yard, fenced on both sides for $1.00 per rod; that bridges 16 feet wide cost $5.00 per lineal foot; that ditch maintenance costs $0.20 per year per rod; that 22-inch tiling will carry this water successfully on this slope. Find whether it is cheaper to use a tile-drain or an open ditch.

5. Calculate the same problem for a drainage area of 5000 acres assuming 54-inch tiling is required costing $3.60 per foot, exclusive of excavation.

6. What factors govern the location of open ditches?

7. Draw a sketch showing the proper design of the cross-section of an open ditch.

8. What is the objection to curves in ditches?

9. Of what importance is the grade of a ditch? How does it affect the capacity?

10. How does the shape of the ditch cross-section affect its capacity?

11. What is the objection to making the side slopes of a ditch vertical? What is the common slope adopted for stable earth?

12. What determines the bottom width of an open ditch? Of a tile-trench?

13. What is the minimum depth for a drainage ditch?

14. State the safe velocities of flow in soils of various kinds.

15. What is the effect on amount of drainage runoff of (*a*) Climate?

(*b*) Rainfall? (*c*) Temperature? (*d*) Topography? (*e*) Size and slope of area? (*f*) Culture of the land? (*g*) Plant life?

16. For what size ditches are hand and team work economical?
17. When should excavating machines be used?
18. Name the various types of excavating machines and state to what type of work each is adapted.
19. Where would you use a centrifugal suction dredge?
20. Discuss the cost of machine work under various conditions.

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CHAPTER XVII

ESTIMATE OF COSTS OF DRAINAGE SYSTEM

The Cost of Open Ditches. — A ditch in Wisconsin, 6 feet wide at bottom, 7 feet deep, 20 feet wide on top (6 × 7 × 20), costs $1600 a mile when there are three or more miles to be dug. A single mile costs $2500 or more. (1917)

Earth excavation is figured at so much for each cubic yard; the more dirt to be removed, the less will be the cost of each cubic yard. The cost may vary from $0.05 to $0.20, depending upon the size of the job, the machinery used, the ability of the contractor, and the character of the excavation.

When figuring on an acreage basis, a distinction must be made between farm drainage and outlet systems. The latter are intended only to afford outlet facilities to farm drainage systems; seldom are they designed to accomplish drainage directly without tiling. Plans for farm drainage systems presuppose that drainage outlets exist or that artificial outlets will be available. It is impossible to build an open ditch, therefore, that will not drain some land without tiling and this, of course, reduces the cost of farm drainage in the vicinity.

The cost of open ditch systems may vary from $5.00 an acre to $25.00 an acre. With the more expensive systems, as a rule, very little farm drainage is necessary; and taking both farm drains and open ditches into consideration, the system may prove more economical than one costing much less but requiring more farm drainage.

Elements of Cost. — The estimate of the cost of drainage work is a comparatively simple matter. It will usually contain comparatively few items, and they may be determined approximately from the local retail price tests of materials and the prevailing contract prices for similar work. Particularly important are those factors of cost which tend to increase or

decrease the cost after the estimate has been made, such as change in wages, unforeseen weather condition, etc. These factors are items which the contractor or bidder must consider and they should always be recognized by the farmer. The price of labor, for example, may fluctuate 30 or 40 per cent during the completing of a single contract.

The factors to be considered in the cost of estimates are therefore: (1) right of way. (2) cost of materials. (3) cost of delivery of materials. (4) cost of administration of contracts. (5) cost of depreciation of plant. (6) cost of financing contract. (7) cost of probable drainage claims. (8) cost of legal expenses. (9) cost of engineering.

Cost of Materials for Drains. — The cost of tiling has already been discussed in the chapter on Materials for Drains. The engineer's estimates should itemize the cost of tiles, labor, materials, etc.

The principal materials needed for drain construction are: (1) tiles for covered drains. (2) gravel for concrete. (3) cement for concrete. (4) grates for outlets and inlets. (5) sewer-pipe for inlets and drains. (6) corrugated pipe for inlets, outlets, and culverts. (7) tile Y's for junctions. (8) sewer-pipe T's for junctions. The cost of concrete is a small part of the cost, and may be estimated as so much a cubic yard. At the present time (1920) the cost is about $15 to $25 a cubic yard. In open drains no material is needed except such as is required for a certain specified number of permanent tile inlets. The cost of tiles quoted by the dealer is f.o.b. the station nearest the factory, and to that price the estimator must add freight charges to the station nearest the point where tiling is to be laid. This makes the cost of tiles heavy where the freight haul is a long one.

In addition there is the cost of hauling and distributing. This is usually figured at 75 cents per ton mile for hauling and $\frac{1}{10}$ cent per pound for each time the tiles are handled.

The best price of the tile manufacturer is subject to discount for cash; and, before the war, this sometimes amounted to as much as 50 or 60 per cent. The general prices on tiles have

been listed in the chapter on Materials for Drains. But the actual cost of the tiles often varies widely from the estimate, on account of the long time that intervenes between the preparation of the estimate and the letting of the contract.

Cost of Labor for Tile Drains. — The most difficult item to estimate accurately is wages. The standard of wages is liable to fluctuate as much as 30 or 40 per cent either above or below the estimate, before the work is completed. Whether the cost of the drain is estimated by the foot, rod, or cubic yard of excavation, the labor item enters, to the same degree, into the unit cost, and it is always uncertain what the cost of this item will be. It often happens, likewise, that the contractor makes a guess at the class of excavation he will encounter, making this factor also uncertain. But this is wholly unnecessary. Common justice demands that a soil-survey be made, so that the exact character of the excavation may be determined. The slight increase in cost will be more than compensated for in the certainty with which the work can be undertaken.

Cost of Trenching. — Trench work is usually estimated by the lineal rod or 100 feet station. It may also be estimated by the cubic yard. The following table from Parson's "Land Drainage" gives the number of cubic yards per 100 foot station for different depths and widths of trench.

TABLE XXII.— WIDTHS AND YARDAGES OF LARGE TILE-TRENCHES PER STATION

Size of Tile Inches	Depth									
	3 feet		4 feet		5 feet		6 feet		7 feet	
inches	inches	cu. yds.	inches	cu. yds.	inches	cu. yds.	inches	cu. yds.	inches	cu. yds
5 and 6	12	11.1	14	17.2	18	27.8	18	33.3	20	43.0
7 and 8	14	12.9	16	19.7	19	29.3	19	35.1	21	45.4
10	16	14.8	17	21.0	20	30.7	20	36.9	22	47.4
12	18	16.7	18	22.2	21	32.4	21	38.9	23	49.8
14	20	18.4	20	24.6	22	33.9	22	40.7	24	51.8
15	22	20.3	22	27.1	24	37.0	24	44.4	25	53.9
16	24	22.2	24	29.6	26	40.0	26	48.0	26	56.0
18	26	24.0	26	32.0	28	43.1	28	51.8	28	60.4
20	28	25.9	28	34.5	30	46.3	30	55.5	30	64.8
22	30	27.8	30	37.0	32	49.3	32	59.1	32	69.0
24	32	29.6	32	39.4	34	52.4	34	62.9	34	73.4

	8 feet		9 feet		10 feet		11 feet		12 feet	
inches	inches	cu. yds.	inches	cu. yds.	inches	cu. yds.	inches	cu. yds.	inches	cu. yds.
5 and 6	20	49.2	22	61.0	22	67.8	24	81.5	26	96.0
7 and 8	21	51.9	23	64.0	24	74.1	26	88.0	28	103.6
10	22	54.2	24	66.7	25	77.0	27	91.7	29	107.6
12	23	56.9								
			25	69.3	26	80.0	28	95.0	30	111.1
14	24	59.3	26	72.0	28	86.3	30	101.9	32	118.2
15	26	64.0	28	77.7	30	92.6	32	108.4	34	125.8
16	28	69.0	30	83.3	32	98.5	34	115.3	36	133.3
18	30	74.1	32	88.7	34	104.8	36	122.2	38	140.4
20	32	78.8	34	94.3	36	111.1	38	128.7	40	148.0
22	34	83.8	36	100.0	38	117.0	40	135.7	42	155.6
24	36	88.9	38	105.3	40	123.3	42	142.6	44	162.7

Trenches narrow as they become deeper, but they are also likely to cave; and the one tendency is assumed to offset the other. In Iowa, before the war, the total cost of tile-trenches from 3 to 12 feet in depth was estimated at $0.40 a cubic yard. The wage-rate was $2.50 a day without board, with $3.50 to $4.00 for skilled tile-layers and foremen. This estimate is an average of many contract prices varying from $0.30 to $0.70 a cubic yard, and includes trenching, laying, backfilling and contractor's profits. Under present (1919) conditions these prices would probably be doubled. The following tabulation shows approximate prices for ditches of different yardage previous to the war:

Yardages	*Cost per cubic yard*
65,000	$0.15
75,000	0.12
90,000	0.11
115,000	0.10
150,000	0.09
200,000	0.08
300,000	0.07
800,000	0.065

Cost of Delivery of Materials. — The cost of delivery is understood usually to include only the cost of hauling from nearest railway station to the point where the drain is being constructed. Tiling forms the large item in the cost of delivery of materials. The business way of paying for this item is to sublet the delivery to some one at so much a ton, withholding a certain percentage to insure completing delivery. Farmers are usually employed to do the hauling, however; and, as a rule, they will not agree to such a contract, but demand full payment as they go. Hard roads, level grades, and stable right of way along the tile-line are conditions favorable to cheap delivery; but one steep hill or one boggy mud-hole on the route will very materially increase the cost of delivery per ton-mile. At $5.00 a day for man and team the cost of hauling averages $0.50 to $0.80 per ton-mile for the first mile, and $0.20 to $0.35 per ton-mile for each additional mile.

Plant Expenses. — These include miscellaneous labor and materials expense and are usually underestimated. Sometimes

shacks are needed for housing or boarding the laborers, in which case the cost is included in plant expense. Besides the cost of all tools, all trench, curbing and bracing, all blasting equipment, derricks, sand-boxes, dredging machinery, barges, and cabins for the same must be included, the latter forming a very large percentage.

Cost of Financing. — This includes interest on borrowed credit. If the job is let by contract, the contractor must furnish a certified check on the amount of which he must either pay or lose the interest. If the district issues bonds to finance the project, the bonds may be sold at a discount or below par to make a ready sale. Personal bonds for the contractors and district officials must be given, for interest on operating capital must be allowed and must enter into the cost just as much as the price of labor and material.

Cost of Administration. — The cost of administration of drainage construction usually amounts to a very nominal percentage of the total cost. On the smaller contracts local contractors fulfill the duties of manager, foreman, and office man in addition to the more expensive work of construction. On larger contracts involving more than $15,000 cost a larger office force is necessary and the local contractor can no longer compete. In such a case administration may amount to 3 or 6 per cent, depending on the character of the job and what is included under this head.

Other Contingent Expenses. — Other contingent expenses are engineering and legal expenses, cost of printing notices, etc., and will amount to about 8 or 10 per cent on a project costing $5000 and upwards. Engineering alone amounts to about 10 per cent for a project of $2000 and to about 5 per cent for a project costing $5000 or more.

Drainage Claims. — These include the following items: (1) Contractor's damage losses, including the cost of damage suits for stock which may fall into ditches, accidents in blasting, etc. (2) Right-of-way damage losses, such as (*a*) actual cost of land occupied, (*b*) cost of fencing right of way, (*c*) cost of necessary bridges for farm operations, (*d*) damages to appearance of

property and convenience of owner, (*e*) loss of value of small tracts cut off and isolated by open ditch.

Three-wire fencing with posts is figured complete at $0.50 a rod, while woven wire is figured at pre-war prices of $0.75 now probably double that value. Bridges for farm purposes may be estimated at $8.00 per lineal foot.

More liberal damages would be allowed if farmers applied the damages to the intended purpose, instead of allowing their stock to cross the ditches and thus destroy them. Deterioration of farm values because of open ditch construction is not a legitimate claim, in spite of the natural aversion some people may have. The inconvenience caused by the ditch is usually no worse than that caused by the natural condition of the land before the ditch was made.

Damages to railways for crossing their rights of way are usually prescribed by law without allowance for delay in traffic, building bridges, etc., which are regarded as inherent public liabilities of railway companies. Only the price of materials used in construction of drains across rights of way is allowed.

Cost of Machine Work. — The cost of open ditch work is figured by the cubic yard. Usually, the greater the yardage to be removed, the less the cost for each cubic yard. On large jobs dredge work is cheaper than team and scraper work, which costs $0.10 to $0.20 a cubic yard, while on small jobs the opposite is true because the cost of building or moving a dredge is quite high.

The cost for each yard for dredge work varies from $0.05 or $0.06 on large jobs to $0.20 or $0.30 on small jobs. This fact shows the wisdom of coöperation and the organization of as much territory as possible under one head.

The following costs for each cubic yard are compiled for different machines described in the United States Department of Agriculture, Bulletin 300.

TABLE XXIII. — COST OF MACHINE EXCAVATION

Size and Type of Machine	Length Miles	Top Width Feet	Bottom Width Feet	Depth Feet	Slopes	Width of Berm	Cost per Cubic Yard
$\frac{1}{4}$ yd. floating dipper-dredge	$3\frac{3}{4}$	22–26	....	6–10	1–1	8	\$.0847
$1\frac{1}{4}$ yd. floating dipper-dredge	....	30	....	5–6	....	....	.0221
$1\frac{1}{4}$ yd. floating dipper-dredge	3	25	18	8	....	....	.41
1 yd. floating dipper-dredge		18	....	2	$\frac{1}{2}$–1	....	.0512
2 yd. rotary drag-line	....	....	4–22	3–12	1–1	....	.1164
2 yd. rotary drag-line	....	....	4–22	3–12	1–1	8	.1273
$1\frac{1}{4}$ yd. rotary drag-line	....	....	4–22	3–12	1–1	8	.1512
1 yd. dry land dipper	....	18	4	$6\frac{1}{2}$	....	....	.1200
Templet excavator	$1\frac{1}{4}$	....	24	3.5–7	1–1	15	.081
Wheel type	165	4	2	4	....	....	.0682
Wheel type	....	$4\frac{1}{2}$	20 in.	$4\frac{1}{2}$	....	....	.0793
$1\frac{1}{2}$ yd. floating dipper-dredge. One year's work cleaning canal	....	....	....	....	....	....	.058
$2\frac{1}{4}$ yd. rotary drag-line 225,000 cu. yds. in South Dakota	....	....	....	....	....	....	.0521
1 yd. dry land dipper-grab-bucket (Levee work)	10	6	....	7	2–1	....	.074

QUESTIONS

1. How may excess fall be taken care of in an open drain?
2. How often should ditches be inspected and cleaned?
3. How should lateral ditches be brought into the main ditch?
4. What are the causes of erosion of ditches?
5. How may ditch erosion be controlled?
6. Why is a uniform rate of flow through the ditch essential?
7. Why is it important to fence outlet ditches?
8. What implements may be used in cleaning open ditches?
9. What factors enter into cost of an outlet system of open ditches?

10. How is cost of large tile-lines affected by depth?
11. How does the amount of yardage affect the cost per yard?
12. What damage claims may a contractor be asked to meet?

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PART III. — SPECIAL DRAINAGE PROBLEMS

CHAPTER XVIII

THE DRAINAGE OF TIDAL AND OVERFLOWED MARSH LANDS

ALONG the coasts there are large areas of land known as tide-lands; and along the rivers leading to the coast we find bottom lands, to some extent affected by tides, and subject to overflow during the high water of early or late spring. In connection with these we may also consider certain areas of peat and muck which occur in the interior valleys. All of these lands are located where there is a remarkably long growing season, and are within reach of water-transportation and markets. They are composed of rich alluvial and vegetable accumulations, and, when reclaimed, are great forage producers. The one important factor limiting their maximum production is an excess of water. The reclamation of these lands is a comparatively quick, safe and permanent aid in increasing the food producing area.

On the John Jacob Astor Branch Experiment Station near Astoria, Oregon, the Oregon Agricultural College Experiment Station has some fifty acres of diked tide-land, for which a tile-drainage system was designed in 1915 and has since been partly installed. Almost no underdrainage has been provided for the tide-lands, although this treatment will double the production of most of these wet pasture lands. Underdrainage, in short, will make it possible to kill out the rushes, grow legumes, and mature cultivated crops, so that crop rotation can be practiced.

Marsh Soils. — Marsh soils usually contain a large amount of organic matter, which gives them a peaty character. Such soils, therefore, are usually light in weight, dark in color, and

very spongy. They take up two or three times their weight of water and shrink upon drying. When dry, such soils usually possess a loose, dusty character.

FIG. 70. An undrained marsh in the Coos Bay section, Oregon.

Tide-Land. — Tide-lands occur as deltas or flat bottoms along the rivers and estuaries influenced by tide-water. The rise and fall of tides cause these streams to back up and overflow

FIG. 71. Same marsh as shown in Fig. 70 after drainage.

at high water, when their sediment is deposited along the bottoms. The coarser material is deposited first, or near the stream, giving rise to what is locally known as "bank land." Such land may be built up to the extreme high-water mark.

Mud flats about the deltas are built up until they are exposed to the air during a part of the time, and water-loving vegetation gains a foothold. When this land attains an elevation above mean tide it may be considered for agricultural reclamation. The vegetation, before diking, consists of tussocks, rushes, sedges, sphagnum moss, and various other water-loving growths. These lands are usually cut by very irregular tide-sloughs, leading from the low parts of the tide-flat out through the "bank lands" into the open water.

Fig. 72. Land enclosed with dyke.

The soil of typical tide-land is a silty muck, containing usually about 30 per cent organic matter, in addition to some inorganic material in the form of fine sandy silt. Fine sandy streaks may be encountered in the subsoil at depths of 4 or 5 feet, forming favorable layers in which to lay drains. Layers of vegetable matter from former sphagnum moss may be encountered in the subsoil, while the surface soil usually has a fibrous peaty structure.

Overflowed or Bottom-Land. — At some distance from the coast, as a slight elevation is attained, the effect of the tide is of minor importance and the soil grades into silt loam. Dark silt loam is the prevailing type on the Columbia River bottom and other stream bottoms of that region; but there is fine sandy loam on some of the river bank land, and occasional layers of silt are encountered in the beds or margins of shallow ponds, lakes, or sloughs. Bodies of peat also occur. The undrained

land of this type may contain 20 per cent of open water, though, under average conditions, the ponds are found to recede to small dimensions in dry weather. Perhaps 15 to 25 per cent may be covered with spruce, vine-maple, willow, steeple-brush, and other growth that requires clearing and grubbing before the land can be cultivated.

In the unreclaimed state, this land is utilized for pasture for a short season. The same land, when reclaimed, should yield 4 tons of field peas and oats, or an equal tonnage of Alsike and timothy hay, as well as good crops of cereals, corn, potatoes, etc. The soil is deep and fertile, and, when utilized for forage crops in connection with dairying, it will safely pay interest on a valuation of $150 to $200 an acre. Under favorable conditions, especially near markets, there will be an increasing demand for this land for truck crops, which may pay interest on twice the valuation that dairying would justify.

FIG. 73. Well laid tile in trench through tide land.

Peat and Muck or "Beaver-Dam." — Peat and muck bogs occur in areas aggregating hundreds of thousands of acres. The central portions of these bogs are usually filled with peat of medium to good depth; and shallow, peaty loam may occur around the margin. The central part, or marsh area, sometimes has considerable in-wash in the surface layers, so that a fairly well-balanced soil has developed. The coarse peat material becomes finer with cultivation. Cattail and bulrushes may

occur on the deep peat in the native state, while the growth on the silty peat or muck is likely to be a mixed growth of willow, vine-maple, alder, and hardhack. The land in the raw state is therefore of very low productive value; but when reclaimed and brought into full production it is very valuable for onion growing and general truck or forage production.

Fig. 74. A dynamited ditch through a bog.

Chemical Composition. — The total supply of organic matter and nitrogen is usually high in these soils, although the nitrogen may be somewhat unavailable in new land. The phosphorous content is about average, though in some soils it seems to be a little below the average and rather unavailable, and super-phosphate is consequently used by commercial truck growers on the " beaver-dam " soil. There is a fair supply of potash in much of this soil, on account of the large amount of silt in-wash. These soils generally respond to potash fertilizers, which can be used with success on the deep peat under certain conditions in normal times. The chemical reaction of most of these soils is somewhat acid. With good drainage, however, the organic acids are removed or their accumulation prevented, so that very abundant crops are secured without liming. Tide-lands in the vicinity of Astoria have responded to liming where Alsike clover was grown, while in some instances the " beaver-dam " soils have not responded to the treatment. Numerous specific tests of the overflowed land indicate that where thorough drainage is provided lime is not badly needed, at least during the first years after reclamation. These soils are generally deep, free-working, of high usable water capacity, and usually productive when drained.

Constructed and Feasible Projects. — Feasibility Surveys. — The length of dike to the acre enclosed is less for compact areas or where only part of the boundary requires embankment. Feasibility of a project depends on location, demand for land, time and cost of reclamation, soil fertility, and probable agricultural value, as well as practicability of engineering features.

In some of the reclaimable marsh lands larger protecting works, such as levees and outlet ditches, have been constructed. Numerous other feasible projects are contemplated or are under process of organization. The lands already diked are in need of further interior drainage and, in many cases, of some supplemental pumping to perfect their reclamation. A large part of this land is capable of being brought into a good state of production in one or two years after drainage.

Dike Location. — Coöperation is important in order to get the largest enclosure with the shortest dike. Dikes should be located, where possible, on land of relatively good elevation; they should run at right angles or parallel to the stream, and should have a wide fore-shore, or strip of land on the outside to break the force of the stream. Natural brush protection can be turned to advantage if a hydraulic dredge is used. Soft slough bottoms and deep peat or coarse sand are not desirable materials for making embankments; and a location can frequently be selected that will avoid running the embankment through such formations. Heavy silt or silty clay are desirable embanking materials.

Construction. — It is generally recommended that the top width of a levee should be twice the square root of the height, and that it should be carried 3 feet above mean high tide. The side slope for good silt should be 3 of run to 1 of rise on the water-side. In sandy soil or in windy locations, 4 to 1 is better. Fine sandy loam or muck can be used successfully for embankment if it is sluiced in with an hydraulic dredge or deposited in a saturated condition with a dipper-dredge. It is desirable, especially with peaty surface soil, to provide a muck ditch, by removing the original earth from the center of the dike-line to a depth of 2 or 3 feet, and then start to build the dike with

excavated subsoil material, so that the dike is keyed in at the center. Logs, sod, and vegetation should be removed; and it is desirable to plow and remove the surface soil ahead of the embankment construction. The muck ditch can frequently be dug by means of the dredge-dipper where all vegetation and logs have been removed, and scalping off the surface soil may be neglected. Where the hydraulic dredge is used it may be desirable to clear a muck ditch and leave the growth on the sides of the proposed levee as a protection against erosion. In crossing an old slough it is desirable to remove the muck in the slough and form the sides at the base of the new levee with piling. Shrinkage of the dike should be allowed for in any case, and will be greater in peat than in silt. Peat may shrink as much as 25 or 33 per cent. Where there are numerous tide sloughs, and the seepage is anticipated, a borrow pit may be provided inside the dike to intercept seepage and lead small streams to a sluice-box, thus reducing the number of boxes.

The earliest dikes constructed in the vicinity of Astoria, Oregon, were built by hand labor, and a good spadesman was considered capable of building a rod a day. Most of these dikes have been strengthened by dredge work since that time. The floating dredge with a boom 80 to 100 feet long is desirable; it should puddle the levee in depositing saturated material. Where small stumps are to be handled, some contractors on the coast prefer the dipper-dredge. In normal times the common price for this work has been about $0.10 a yard. Suction-dredges have been used on the Columbia River during recent years and have proved considerably more economical than the floating dredge fitted with boom and dipper.

Maintenance. — The embankment can be smoothed down with scrapers and, in two or three years, can be seeded over so as to afford good pasture. The presence of stock will tend to keep out rodents and pack the embankment, while the sod will protect from erosion. Where the embankment is subject to wave-action, rip-rapping with stone or lining with rows of piling to which a chain of logs is attached, will usually afford protection.

Tide-Boxes. — The primary consideration in providing a tide-box is to allow ample capacity. Failure to do this has resulted in dissatisfaction and loss. Inquiry into the capacity of tide-boxes in the vicinity of Astoria and a study of the areas served by boxes considered of ample capacity, developed the fact that an area of about 12 or 13 acres was being drained for each square foot of tide-box. These sluice-boxes should be strong, tight, and firmly placed. They should be located on a firm foundation and be provided with piling to which mud-sills are bolted at mean low tide. Wing-walls should be provided and should extend well into the levee banks. The gate should be counter-weighted so as to move easily, and should set tight. Tongued and grooved piling can be used to coffer-dam the water while the pit is being excavated for a small tide-box, which can finally be set at the time of low tide. The larger boxes can be installed with the aid of a dredge at favorable tide. It is recommended that the gate be made to fit tightly by the use of good rubber belting, and that the hardware used be galvanized iron or hard brass with link-hinges for the gate. Where the fall is greater than is necessary, and the land within the area served by the sluice-boxes is low, it is frequently desirable to allow the turbid hill-water to spread out over the low area and deposit silt. Water can then be siphoned off, by having the upper end of the sluice-box carried above the surface of the ground so as to draw off only the clear water. Creosoting will protect lumber from deterioration.

Fig. 75. A large concrete tide box at Clatskane, Oregon. There are five outlets each five by six feet.

Outlet Ditches. — Marshes on the coast and the lower Columbia frequently do not require any extensive amount of interior open ditches. An upland stream may enter and spread

out on the marsh or traverse it in a meandering course. A large stream may need to be straightened by dredging, or its sides may require banking to carry the water across the marsh to the open water on the outside. A small foot-hill ditch will frequently serve to pick up the hill-water along the margin of the marsh, and deposit it by gravity or through a separate sluice-box at the end of the dike. In such a ditch, settling-basins may need to be provided for deposition of silt brought in from the hills. Some marshes in the Willamette Valley require an outlet ditch through the trough of the marsh and smaller foot-hill ditches around the marsh borders.

FIG. 76. Small wooden tide box.

Outlet ditches should be made of ample depth to provide for the discharge from tile and should have broad side slopes. They should be reasonably straight, and have as uniform a grade as practicable. The size of the ditch may depend somewhat on the grade. In most of the marsh land the fall will be limited and the size will depend mainly upon the amount of water to be handled. This is affected by amount and distribution of rainfall, weather conditions, topography, the size of the watershed area, the nature of growth, and the kind of soil. The dredge used for the embankment will generally be used for interior ditches, unless perhaps a smaller one is required. A dredged ditch cannot be made narrower than 6 or 8 feet. Attention should be given to these interior ditches to guard against erosion, caving and injury by stock.

Pumping-Plants. — The mean tidal fluctuation on the Pacific Coast is but 5 to 7 feet, while on the North Atlantic Coast it is much greater. On the lower stream courses there are only a

few hours, between the tides, during which sluice-boxes may operate. Again, much of the marsh land is within 3 feet of the mean water-level outside; and complete drainage, under such conditions, requires some pumping.

The centrifugal pump is most used for this purpose, as it is light and simple, and handles large quantities of water. Pumps for drainage should be set as low as possible while still keeping them above water. The plant should be carefully located. A concrete base should be provided with threaded anchor bolts, the latter should have nuts below base plates, for leveling up before completing the concrete work. The suction and discharge-pipes should have few turns and these should be of large radius. The pipes should be no longer than necessary, and, in order to save power, should discharge at as low an elevation as possible. The supply-ditch will usually be a large tide-slough which provides some storage capacity, and this should have a trask rack at the approach to the intake pipe. The best modern pumps have double suction and split casing. Provision should also be made for priming the pump (Fig. 9). The capacity required may vary from $\frac{1}{5}$ to $\frac{4}{5}$ acre-inch to the acre in twenty-four hours $\frac{1}{5}$ to $\frac{1}{4}$ inch has been found ample capacity for diked bottom-land in the vicinity of Portland. This is equivalent to 5 or 6 second-feet per square mile. The capacity may be somewhat less for meadows than for crops that require complete drainage for maturity, such as potatoes and onions. The power required will depend on the lift, volume and amount of friction. Each cubic foot lifted 8.8 feet per second represents one water horse-power and this sum should be doubled to allow for 50 per cent efficiency. Where electricity can be obtained at a moderate rate, a direct-connected motor in conjunction with a centrifugal pump makes a very satisfactory installation and requires very little attention. Where electricity cannot be obtained, gasoline or distillate engines may be employed. A small portable pumping outfit may be located on a barge and used for drainage or supplementary irrigation. A small pump-house should be provided to protect the plant from the weather.

Cost of pumping includes (1) fixed charges, such as interest and depreciation on the first cost of the plant and (2) operating expenses, including labor, fuel, and lubricating oil, which collectively make up the total annual cost. This cost, distributed over the area, would give the total annual cost to the acre for pumping. Pumping-plants will be used more and more in connection with drainage and supplementary irrigation on the peat and overflowed lands, and, as a supplement to the sluice-boxes, to provide complete drainage near the coast.

Interior Drainage. — Very little interior drainage has been provided in diked lands and almost no underdrainage has been employed. On the tide-lands an occasional box underdrain has been installed. The tile-drainage system on the Branch Experiment Station at Astoria, Oregon, is, so far as can be determined, the first thorough tile system to be installed on tide-land on the west coast. In order to illustrate the problems to be encountered in draining such land and to explain the preliminary results of the experimental part of the system, its installation will be described.

In laying out this drainage system the existing sloughs were all sketched, and were taken into consideration in laying out the system for the main body of the farm in a random or natural system of drainage applicable to ordinary farm conditions. A soil-auger was used to study the subsoil and ground-water conditions, so as to locate drains where they would serve most efficiently.

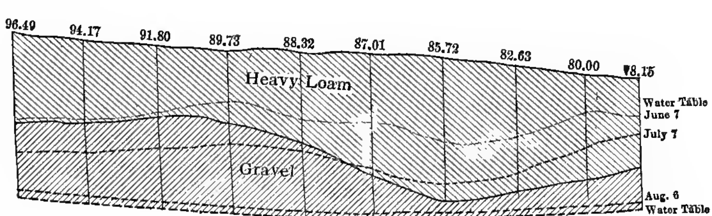

FIG. 77. Water table and substrata in Powder Valley, Oregon.

Excess water on this tide-land comes from (1) runoff from the hills and related springs near the base of the uplands, (2) seep-

age through the dikes, (3) excess ground-water due to precipitation on the low land itself. It was decided to run a main drain in the direction of the dike, and near the inner side of it, to intercept seepage that appeared to be taking place there. This also led to small tide-sloughs which had been closed off in constructing the dike, and contained standing water all summer, due to lack of outlet. Laterals were arranged to take up these sloughs, and a foothill ditch and underdrain were arranged to intercept the water from the upland. Additional laterals were placed at fairly regular intervals to serve the remainder of the low interior fields.

FIG. 78. Meadow land in the Powder Valley, Oregon.

Design of Underdrains. — The first step in designing a drainage system should be an examination or preliminary survey with the aid of a soil-auger and level. The objects of this examination are to learn the subsoil and ground-water conditions, to determine the lay of the land and location of outlets, and to aid in designing a drain system. In arranging interior tile systems for tide-land, where the field is broad, and low in the center, it is best to run the main through the center of the marsh and bring laterals to it from both sides. Where the field is low near the hill, and subject to seepage from the levee, mains of good capacity can be put along the edges of the marsh near the dike and at the base of the hill, and the laterals led to these mains. In the Astoria Branch Experiment Station drainage system, a section was arranged to determine by experiment the best depth and frequency for laterals.

In designing field drains for overflowed land, it may be necessary to carry an open ditch or tile along the inner side of

the levee to collect seepage, and connect the small depressions and sloughs leading the excess water to the pumping station or sluice-box. Where there is little seepage, the interior drainage on the overflow land will usually be only a random, or natural, system of drains to take care of the swales and depressions.

FIG. 79. Swamp land in Central Oregon before reclamation.

The ordinary peat bogs will require an outlet ditch through the trough or center of the bog and a foot-hill ditch or tile-line around each side. From these, parallel laterals may be run in such directions as will thoroughly drain the interior or remainder of the bog, with the least expenditure for junctions, double-drainage, or outlets. While the outlet ditch and foot-hill ditch may give sufficient drainage for pasture and meadows, if augmented by an open ditch at intervals of 300 or 500 feet, this will not permit complete drainage. To grow such crops as onions and potatoes properly, and draw off the water quickly in the spring, so that early planting can be accomplished, additional laterals 3 to 5 rods apart, arranged in parallel series, will be needed.

FIG. 80. Same land shown in Fig. 79 after reclamation by drainage.

Experiments Relating to Depth and Frequency. — As the underdrainage of tide-land is a comparatively new enterprise, it seemed desirable to arrange a section of the drainage system on the Branch Experiment Station to serve as an experiment

to determine the proper depth and frequency for laterals in tide-lands. Laterals were accordingly arranged at a depth of about 4 feet and spaced 100 feet apart; others were placed $3\frac{1}{2}$ feet deep and 75 feet apart; while still other laterals were placed 3 feet deep and 50 feet apart. Sufficient laterals were placed in each group to provide one interior or guarded lateral, the discharge of which could be measured. It was planned to measure the discharge of each of these guarded laterals, together with the outflow from the entire experimental system, and also the distance to which these tile-lines, placed at different depths and distances would affect the water-table in a reasonable length of time after heavy rains. The water-table is being studied by means of a row of observation wells extending across the tract at right angles to the experimental laterals. In order to determine the yields of crops grown, the tract is divided into plats, having laterals at greater and lesser distances apart.

From the preliminary results at hand, it appears that fairly good drainage will be provided where the tile-lines are placed 4 feet deep and 5 rods apart. Where this depth of outlet cannot be obtained, it may be necessary to put the tile-lines 3 feet deep and 4 rods apart to accomplish the same purpose.

In the overflowed land, parallel laterals are not likely to be needed. Here, a random system of drains, running through the main swales and ponds at a depth of 3 to $3\frac{1}{2}$ feet, will prove to be sufficient.

In the peat, or beaver-dam land, fair drainage for grasses may be provided by open ditches from 300 to 500 feet apart and 5 feet deep. To provide for early planting, however, and to bring this land into full production, or to obtain complete drainage for the ripening of crops such as onions and potatoes, it has been found desirable in practise to have laterals $3\frac{1}{2}$ to 4 feet deep and 3 to 4 rods apart, and in addition, to take care of any seepage or spring-water not collected by such parallel laterals. Four feet is a good minimum depth, as peat soil may shrink $\frac{1}{4}$ of its volume, due to more rapid disintegration following drainage. If the water-table recedes below the tile-

base, such shrinkage is more apt to interfere with the grade of the tile-line. Flash-boards may be used to raise the water in drains and cause sub-irrigation at intervals.

Studies Relating to Size and Grade. — The size and grade for tiles are closely related to the depth and frequency, and are affected mainly by (1) character of soil and subsoil, (2) amount and distribution of rainfall, (3) topography and amount of runoff, (4) kind of crops, (5) prevalence of underground water, and (6) grade. Experiments by the experiment stations in the Willamette Valley and on the coast, where the outflow from different tile systems has been measured, have developed a standard of $\frac{1}{2}$ inch to the acre in twenty-four hours, as providing good drainage capacity under Willamette Valley conditions, unless there is additional spring-water or some unusual condition to contend with. Pumping-plants on the overflowed land having capacity to handle $\frac{1}{4}$ inch or $\frac{1}{5}$ inch of water in twenty-four hours are considered adequate where operated regularly and for sufficient intervals of time. From preliminary data at hand, it appears that the main tiling on tide-lands on the north coast of Oregon should have capacity to handle an inch to the acre in twenty-four hours. On the south coast, on account of the lesser rainfall, $\frac{3}{4}$ inch to the acre in twenty-four hours should be a reasonable capacity.

In the experimental tile system at the Branch Station near Astoria, the main drain is practically 6 feet deep at the outlet, while the upper end of the most distant lateral is less than 3 feet deep. The elevation of the land near the outlet is about 1 foot higher than in the most remote parts of the drainage system, which are 1200 feet distant. The fall used for the main drain is 0.16 of a foot for each hundred feet, and the laterals have a fall of 0.2 of a foot for each hundred feet.

Construction of Underdrains. — Underdrainage on marsh land can best be installed in the dry season, except where special conditions make other seasons suitable for the work.

The drainage system on the Branch Experiment Station at Astoria is practically the first thorough tile system on the west coast on such land, and as numerous difficulties are en-

countered in tiling tide-lands, this system will be described in some detail. The drainage system was designed by the writer, and installation has been in charge of former Superintendent A. E. Engbretson, who describes the construction work as follows:

"The tide-land has buried in it large amounts of logs and debris, especially in the older portions of the land. In digging, these are often met with and require considerable time in cutting. All logs should be cut entirely in two, even if partly below the tile-base. In deep ditches, such as required by the main, the tiles should be laid as soon as possible because of the fact that after a heavy rain the sides will move toward the center, thus making it very narrow. All tools should be sharp so as to cut the fibrous roots in the land."

FIG. 81. Tile land in the Klamath Basin, Oregon, protected by dykes.

"The tile-base is of such a nature that it is inadvisable to stand on it while laying, unless it be done promptly and in very dry weather. There is generally some water present; and any walking will make the base soft and uneven. It is also unsatisfactory to stand on the tiles while laying. This will cause them to be uneven and improperly placed. In order to avoid these difficulties, a plain board, 1 × 8 × 36 inches was beveled at one end, and a strap for the toe was nailed on top. When laying tiles, a person stood on this board and worked it back as the tile was laid. This left a smooth base on which tile could be properly laid."

"There are places in the tide-land that are very soft. These are perhaps old slough beds that have been filled. Tiles cannot be laid on this soft bed. A plank, 2 × 12 inches, is sunk below the tile-base so that it forms a solid, even base. Where these spots are not wide the ends of the plank should rest on firm ground. If they are wider, and two or more planks are

necessary, blocks should be placed under the ends so that there will be no sinking. All places that are soft and seepy should be provided with planks underneath the tile-base so that there will be no settling below grade."

All tide-sloughs having water should be taken into consideration. For short, irregular tide-sloughs, a slab-drain can be employed. Rails and tussocks can be placed in old sloughs after which they may be plowed full. For all the main drains, where land is valuable, it will be cheaper in the long run to use tiles, even though a slab has to be laid underneath to keep the tiles in place.

Laying the Tiles. — Tile-laying should begin at the outlet and proceed upgrade just as soon as the trench is finished to grade. A carefully finished trench facilitates laying the tiles. Tiles should be placed in a straight line and true to grade, with ends fitted snug on top and flush at the inside lower edge. Openings of more than $\frac{1}{8}$ inch should be covered with pieces from a broken tile. Tiles may be rotated to fit, and imperfections may be taken advantage of in making slight turns. Curves may be fitted in by chipping off the inside edge of a tile with a chisel and hammer. The Y's for junctions can be constructed, but it is better to buy them ready made. A board or plank should be set under the tiles wherever the tile-base is in the least unstable. It is advisable to guard against obstructions and disturbance of the tile by blinding in each evening during construction.

FIG. 82. Tile drain filled with silt due to poor outlet.

Filling the Trench. — After the tiles are blinded in, or partly hidden with loose earth, it may be desirable in fine-textured

soil to cover them with a layer of rushes, straw, or sods, to facilitate the entrance of water into the drains. Rushes or sod placed over the tiles will be very slow to decay and will prevent the joints from filling up with clay or silt. The trench can then be backfilled by plowing off the sides with a plow equipped with long eveners, so as to allow one of the horses to walk on each side of the trench.

Details of Construction. — Outlets should be walled up and screened, or, if liable to inundation, should be provided with a flap gate, counterweighted so it will close out a back current. Laterals should be brought into the main drain with a curve and a slight fall. Silt-basins and surface inlets should be 3 feet in diameter, so that a person may enter to clean them out, and should be covered or screened.

Sub-Irrigation. — In open ditches or tile-lines, where it is desirable to provide sub-irrigation by checking the outflow for a couple of days every two weeks in the earlier part of the dry season, flash-boards may be provided.

Operation of Experimental System. — H. R. Taylor, the present superintendent, of the Astoria Branch Experiment Station, describes the operation of the completed portion of the drainage system as follows:

Water-table.— The difference between the effect of experimental laterals 380 feet long, and respectively 50 feet (Lat. B) and 100 feet (Lat. C) from their neighbors, was studied by means of borings or wells. "Readings were taken during the last week in September before the fall rains. At that time the water-table was at a depth of more than 5 feet. Wells were bored to a 5-foot depth. Readings were made, October 5, 1918, after a two-day rain, and on November 27, 28 and 29, during and after a storm period."

"*Weather.*— October 4 and 5, rain; November 25 and 26, rain; heavy showers during the week previous; November 27, frost followed by clear weather; night of November 27 and 28, heavy showers; November 28, cloudy; November 29, clear. In adjacent fields there was a considerable amount of water standing in pools on the surface. There was no water

on the surface of the drained field. Data for November 28 will also apply with fair accuracy to November 26 and 27, as the outflow for those days was quite constant."

"*Yield.* — On the drained field, a crop of oat and pea hay yielded 5.1 tons to the acre. The best growth was made nearest the drains; and the plants were shorter and the number was less to the square foot, in proportion to the distance from the drains. Adjacent to the main drain, the plants reached a height of over 6 feet; at the point farthest from the main, a height of 4 to 5 feet. An undrained field of oats and vetch, adjacent to the drained field, yielded approximately 2½ tons of hay to the acre, but was a little patchy on account of wet spots during the early spring."

Cost and Profit. — Cost of the tile system as described wil average about $25.00 an acre. The first crop, 5 tons field-pea hay to the acre, was double the yield on the portion not yet tiled. This crop was worth $25.00 a ton at local prices, so that the cost of tiling was repaid in the first crop. Tiling will double the productive value of the greater part of the marsh lands in western Oregon. Much of this land is already provided with protecting dikes for main outlet ditches, but is in need of tile.

A peat-bog near Troutdale, containing 7 acres, was drained, and the following costs submitted by the owner:

Tile — 5000 feet of 3, 4, and 5-inch, costing	$129.00
Freight bill	12.00
Hauling of 12 loads at $2.00 per load	24.00
Digging 306 rods at $0.30 per rod	91.80
Total	$256.80

or $36.70 per acre.

The owner states that, until they drained the land, they did not work the field on account of wet places. The drainage system was installed in 1912, and during the following winter the main ran full for several days at a time. The next year, according to the owner, the field produced $76.00 worth of potatoes to the acre. A stand of clover was obtained after drainage, although this had proved impossible before drainage.

The owner says that the first two crops fully paid the cost of the improvement.

QUESTIONS

1. Describe the character of tide-land. Overflowed land. Peat-land.
2. Explain the general chemical composition of marsh soils.
3. What advantages do marsh soils offer as a field for reclamation?
4. What is a reasonable percentage of shrinkage in a peat soil?
5. Discuss points to consider in construction of a levee.
6. Describe the construction of a tide-box.
7. What are the main points to consider in designing a pumping-plant?
8. What factors enter into the total annual cost of pumping for drainage?
9. What are the main points to consider in designing interior drains for tide-land?
10. Give results of experiments relative to depth and frequency for underdrains in tide-land.
11. What is a suitable drainage coefficient for main tiling in tide-land?
12. What is a minimum grade and size for lateral tiles in tide-land?
13. What precautions should be observed during construction to secure a firm tile-base?
14. How may sub-irrigation be accomplished in marsh soils?

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CHAPTER XIX

THE DRAINAGE OF IRRIGATED LANDS

In the irrigated region, the chief types of land needing drainage are (1) soils that were seriously alkaline in the virgin state, (2) those that were water-logged or marshy in the virgin state, and (3) those that have become water-logged and more or less alkaline as a result of the seepage, deep percolation, and waste connected with imperfect irrigation. Many large drainage districts are in the semi-arid sections of the West; and about 15 per cent of the irrigated lands need drainage. The majority of Irrigation projects face the drainage problem to some extent. In Yakima County, Washington, there are over 52,000 acres included in drainage districts, exclusive of Yakima Indian Reservation, which has 59 miles of large open drains. In every irrigation project the disposal of seepage and drained water must be considered.

There is a tendency for the third class of lands to increase in area throughout the lower-lying and finer-textured soils of the irrigated districts. Alkali vegetation, such as salt-grass and grease-wood, is apt to appear in the affected areas. Since any hard-pan layers are, as a rule, fairly well dissolved by the years of irrigation, and porous layers can usually be encountered in the deep subsoil, drainage by intercepting or collecting channels is usually feasible. Later, when the soil has become water-logged, and the presence of alkali is apparent on the surface, it takes a much longer time to bring these lands back into profitable production. Drainage should be promptly provided at the first appearance of injury, as delay at this time is suicidal.

Lands known to be injuriously alkaline should be provided with drainage and irrigation at the same time and before cultivation. The productive value must justify the total cost of rec-

lamation. The character of the soil must be such that drains will operate, in order to render reclamation of such lands feasible. Some of these alkaline, grease-wood lands at the higher elevations, or remote from outlets, and having fine-textured, impervious subsoils, have not as yet proved amenable to drainage under normal conditions.

The marsh lands of the mountain region include wild hay meadows of dark silt loam, or peaty silt loam and tule beds (bulrushes), growing on peat. These soils are, as a rule, readily drained, though in some cases supplemental pumping is necessary. A layer of chalky material, more or less diatomaceous, is frequently found; but the fifth or sixth foot is usually medium sand which facilitates underdrainage. With water fairly well controlled on these marshes in experiments by the Oregon Station, we have been able to substitute tame grasses and clover for the wild hay, and to double the former yield with less than half the amount of irrigation that is ordinarily employed on the wild meadow.

Drainage Practice in the West. — Those familiar with drainage practice in the Central States will be chiefly interested in the special methods required for successful drainage on irrigated lands. These methods were developed partly by the former Office of Experiment Stations; but most of the western experiment stations have contributed to our present knowledge of subject.

Arid soils have not been subjected to leaching or development of veins for water, and have not had sufficient moisture to produce organic growth and consequent accumulation in the surface-layers. The soil may be similar for several feet down; hard-pan is *not common*, but, where present, interferes with the movement of free water, often causing a local water-table. Gravel layers occur and are quickly moistened to the excess point and afforded a channel for excess water. The maximum amount of alkali usually occurs where the water-table is 30 to 50 inches from the surface, so that extensive capillary action without resolution occurs. Drains must be provided that will lower the water below the capillary limits of the soil.

The source of excess water is usually seepage from irrigation laterals, deep percolation from wasteful irrigation, or surface waste water.

In Planning a Drainage System for irrigated land, numerous deep borings and a few test pits will be necessary. The water-table will fluctuate considerably during the irrigation season, so that numerous carefully located observation wells will be helpful. The design of a drainage system for irrigated land will depend on many factors, the most important of which are, type of soil, runoff, topography, amount of irrigation, and source of damaging water.

The minimum depth for drains in irrigated lands is fixed by the range of capillarity, which is less for sandy soils than for other types; but it should rarely be less than 6 feet, while the main drains should be much deeper. The distance between drains may be relatively greater than with rainfall farming, and depends upon soil and underlying formations. It may vary from a few hundred feet in loose soils, to over a mile where continuous formations of open ground are found. Strong clay tile is the material to be preferred for such underdrains. An intercepting drain should be used wherever possible, to gather water from higher lands, and may relieve lands for as much as ½ mile below. These lines should be located near the upper edge of the affected area. Relief wells can be installed to bring the seepage-water up to the intercepting drains, if seepage is in porous layers over 9 feet deep and under pressure. Again, where hard pan interrupts percolation into unsaturated gravelly layers below, the relief well can be employed as a vertical drain. On flat areas of loam, parallel lines may occasionally be employed and placed 440 or 660 feet apart, so as to serve ½ or ⅓ the width of a quarter section. Any important outlets should, of course, follow the natural depressions in the land.

The capacity must be greater in coarser soil sand where the duty of water is low. Capacity to handle ⅓ of the irrigation flow has been recommended. To provide ample capacity for flushing, some writers have advocated as high as a second-foot

capacity for 100 to 160 acres. The maximum discharge from drainage districts in irrigated land varies from less than one second-foot to over 5 second-feet per square mile, and the total runoff varies from less than 20 to over 60 per cent of the water applied. Closed drains are preferable to open ditches where the volume is not too large, even if the first cost of the former is somewhat more. Laterals should be constructed of 5 or 6-inch tiles.

The deep trenches required are subject to caving, especially in water-logged land, and shoring may be required during construction. Trenching machinery will usually be provided with guard casings but is not successful where soft bottom is encountered. The drainage should be rapidly constructed, a short section at a time, proceeding from the outlet. Pits for flushing and cleaning out the silt and roots are needed every 40 or 80 rods in the finer-textured soils which are liable to cause silting; and bedding the tile-line with fine gravel is frequently desirable. Pumping into irrigation laterals is resorted to in special cases, to dispose of the water where no outlet is close at hand. This water is usually not bad for irrigation when diluted with the other water of the lateral. Care must be taken to refill the trench completely and provide the flume-crossing for irrigation laterals passing over underdrains.

Fig. 83. Drainage water used for irrigation of lawn and garden.

The cost of drains 6 or 7 feet deep in the irrigated section, where some hard-pan is frequently encountered, usually runs from $0.50 to $1.00 a foot. The small number of lines employed makes the cost of drainage normally about $10 to $30 an acre, with the average close to $20.

Treatment of Alkali Land. — Alkali land should be leveled into regular or contour checks after drainage, and submitted to copious flooding, which will cover the surface entirely without excessive ponding. Should any high spots be missed, the alkali is apt to move up, or be drawn out by capillarity, from these unflooded summits. During reclamation, deep cultivation is desirable, in order to restore the structure of the soil, aerate it, and keep the alkali down. Calcium sulphate or other sulphate will help keep the salts in soluble form and lessen the tendency to puddle. Sweet clover can be established by keeping the surface moist and the alkali dispersed until the crop shades the ground. This crop will add humus and loosen up the soil below the plowed strata, thereby facilitating drainage. Water should leach through all the land and be kept moving down without percolating into the drainage systems in streams. Oats can be used to follow the clover after the latter is pastured and plowed into the land. Two years is the average time required for reclamation; yet we have designed drains in water-logged alkali-lands, where a large grain crop was obtained the following year, and repaid the entire cost of drainage.

Fig. 84. Trees killed by seepage in the Snake River Valley.

As an example, Project No. 43, designed by the Oregon Agricultural College, on an alkali area in the Crooked River Valley is here described. Before this land was drained it was regarded as practically worthless because of the presence of black alkali in the soil. Four acres of black alkali were drained at a cost of $34.63 per acre. These figures were given by the owner, who says, " The tiling easily drains the land, and would

have served 6 acres instead of 4 if a deeper outlet could have been secured and deeper drainage provided. Securing the tiles in carload lots would have reduced the expense $12.00 an acre. Before the land was drained, the crop in 1914 for the 4 acres was 20 bushels of barley, or 5 bushels an acre. The crop in 1915 for the 4 acres was 208 bushels of wheat and barley, or 69½ bushels an acre. Placing a value of $0.80 a bushel on this crop, the result is $222.70, which, less the cost of drainage, $138.50, leaves $83.90 net gain this year from the above operation. From these results we believe that drainage is an unqualified success. This tract we tiled only as an experiment; and we intend to drain 40 acres more as quickly as possible. There are few investments which will pay as well."

The Umatilla Drainage District near Stanfield, Oregon, reclaimed land which had been abandoned to alkali, at an average cost of $15 an acre; and the land is now valued at $150 to $200 an acre. Coöperation is often necessary in draining irrigated land, and the cost is lower on larger districts.

During the period of 1901–1906, the United States Bureau of Soils made a number of experiments with regard to the leaching of alkali. Experiments were carried out in several states; but perhaps the most important was on a 40-acre tract near Salt Lake City. It was tiled, checked and flooded. In September, 1902, before flooding, the uppermost 4 feet of soil contained 6651 tons of mineral salts. After applying 410 acre-feet of water there remained, in October, 1904, only 878 tons of salts. About 86 per cent of the total salt content had been removed.

In 1913–1914, the Drainage Division of the United States Department of Agriculture made similar experiments on a tract in the Boise Valley, Idaho, and one in the Grand Valley, Colorado. The first mentioned tract contained 40 acres, but only about 23 acres were irrigated the first year after drainage. On the portion irrigated, the uppermost 5 feet of soil contained 753 tons of alkali. During irrigation the water applied carried 0.54 tons and the drainage water carried 2.59 tons of salt per acre-foot. During the first year, soil analyses showed that

150 tons of salt had been removed. The results during 1914 were about the same.

The experimental tract in the Grand Valley contained 10 acres. Soil analyses of the uppermost 6 feet of soil showed that the surface foot contained 3.29 per cent of alkali, and that the lowest percentage was 2.12 in the third foot of depth. Tile-lines were installed, contour checks were constructed, and the tract was flooded continuously. During the first season, the alkali content of the uppermost 6 feet of soil was reduced by 1.314 tons. The alkali in the surface foot was reduced by 75 per cent. Much of the alkali removed did not pass out through drains, but merely washed down to greater depths.

A new experiment is underway near Vale, Oregon, where several hundred pounds an acre of sulphates are being tried to facilitate laundering alkali out. The outlet ditch has been very economically built by a sluicing process.

It is possible, then, to reclaim much of the land affected by alkali. Where the concentration is low, the soils open and porous, and the drainage systems efficient, it is not a difficult task; but with close, tight soils which have become puddled by black alkali, and where the percentage of salts is high, it is a difficult and expensive undertaking, requiring two or three years of work before there is much return.

Fig. 85. Sweet clover on Alkali land Klamath Basin, Oregon.

The tule-marshes may be burned over when wet underneath, so that the soil is not destroyed. This removes the heavy mat of large vegetation, provides some available plant food, and helps to neutralize any acidity. Such land as that in the Klamath region is usually plowed rather shallow the first year, and cropped to oats for hay, 3 or 4 tons an acre being realized.

After one or two crops of grain, the land is seeded to Alsike clover and timothy, which yields about 3 tons an acre. On one coöperative experimental tract of 1000 acres of diked marsh land, in that section, there was pumped off an acre-inch an acre in early spring, and pumped on about 10 acre-inches an acre for irrigation, later in the season.

Relation of Economical Irrigation to Drainage. — It is possible to eliminate percolation losses almost entirely, by means of scientific irrigation, water being applied to the land without exceeding the useful water-retaining capacity for the root zone. During 10 years of irrigation on the silt loam soils at the Oregon Experiment Station, no irrigation water has percolated below the 7-foot layer, as far as could be detected by soil-moisture determination. Medium sand in 6-foot lysimeters, at the Umatilla Experiment Station, retain about $3\frac{1}{2}$ inches depth of water per irrigation, for the 6 feet of soil, while silt soil in other lysimeters, receiving the same amount of irrigation, lost nothing by percolation. Light, frequent irrigations and short runs are necessary for these coarser soils, and with good control percolation is nearly eliminated. A man's land may be injured by the carelessness of neighbors at higher elevation. The district Drainage Law of Oregon, in apportioning cost of drainage, provides for assessment of contributing damages against land and ditch owners on higher land. A small percentage of waste is held to be justifiable, where water is only moderate in price and under certain economic conditions. It takes time to improve the practise of the whole community. The irrigator must be made to realize the necessity of preventing injury to the land, and irrigated lands must be drained at

Fig. 86. Deep drains in alkali land in the Snake River Valley, Oregon.

the first sign of damage. Delay in this matter is criminal negligence.

Seepage from canals and laterals is a more common source of excess water. Ditches of proper grade have a tendency to become sealed up with age; but, as water becomes more valuable, clay-puddle, heavy oil, or concrete may be employed for lining ditches. In Oregon, canal systems commonly lose 30 to 50 per cent in delivery. Farm laterals $\frac{1}{2}$ mile long have often been found to lose 15 or 20 per cent, while perhaps 10 to 15 per cent is allowable for deep percolations and runoff into fields devoted to general farming.

More economical use of water is secured by using legumes and manures to build up and maintain the usable water-capacity and available fertility of the soil and by practising a crop rotation, including occasional deep cultivation and a diversity of crops. These things help to control transpiration and lessen the water requirement of crops. It has also been found helpful to practise rotation in the use of irrigation water and to base the assessment for maintenance on the amount of water consumed. Less water is required if it is applied just at the right time and by proper methods to well-prepared land.

The application of any needed fertilizer will lessen the total water and irrigation requirement.

Much of the seepage-water may be used again for the irrigation of land in the lower parts of the valleys; and, in time, a combination of natural and artificial drainage, together with more economical use of water, will contribute greatly to the development of highly profitable and stable agriculture under irrigation.

QUESTIONS

1. What three classes of lands in the arid regions need drainage?
2. Why is drainage of irrigated lands acquiring greater importance?
3. Why is it necessary to drain irrigated land promptly when needed?
4. Describe wild meadow lands, giving their nature, vegetation, and crop adaptation with water controlled.
5. What peculiarities of arid soils affect percolation and drainage?
6. How should drainage qualities of arid subsoils be studied?

7. What is a good average depth for underdrains in irrigated land?

8. How far apart may drains be placed, if of average depth, in irrigated land?

9. What factors affect capacity of underdrains in irrigated land?

10. Why do lateral tiles need to be fairly large in irrigated land?

11. What treatments help to improve alkali land after drainage?

12. Give an example of successful underdrainage of irrigated land.

13. To what extent may artificial drainage be assisted by economical use of irrigation water?

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CHAPTER XX

MISCELLANEOUS DRAINAGE PROBLEMS

BESIDES the drainage of agricultural land, there are a number of special drainage problems in connection with district drainage which need attention. Such problems are, for example, the drainage of barnyards, the drainage of buildings, lawns and gardens, the disposal of sewage effluent from septic tanks and sewage filters, and the drainage of public and private roads.

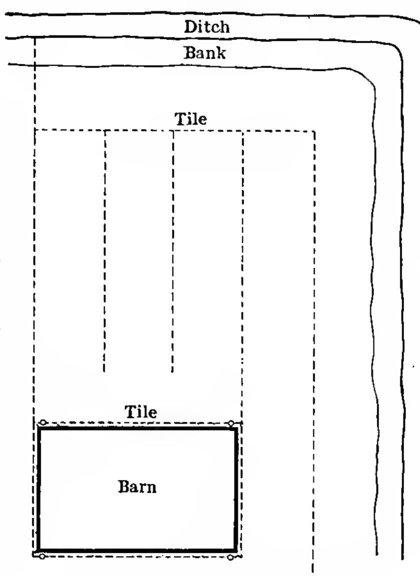

FIG. 87. Plan of drainage system for barnyard.

Drainage of Barnyards. — For draining a barnyard, there should be a dike, a ditch, or tile-line around the farmyard to shut out any water that might otherwise run in from the outside, beeause half the battle in any drainage project is to divert the water before it gets upon the land. The feed-floor in the barnyard should slope gradually to a catch-basin which carries the water below. Water from the eaves should be collected and carried through a "down spout" to a catch basin. This basin should be large enough to take the water and allow the silt to settle. The inlet should be protected by grating. Underdrains may be used as in field drain-

age; but they will usually prove less effective in barnyards on account of the puddling action of the stock in muddy weather. Tile-drains, if used, should be placed $2\frac{1}{2}$ feet deep and 2 rods apart, and the trench filled with gravel, after which the yard should be graveled.

The Drainage of Buildings, Lawns, Gardens, and Orchards. — There should be a drain leading from all basements; and the basement of each substantial farm building should have a drain-tile laid just outside the base, a few inches below the lowest point of the foundation. Lawns and gardens in wet climates will be benefited by tiling. Intensive truck crops will often justify very thorough drainage. Orchards affected by excessive water and erosion also require tiling. The tiling should run in the center of spaces between trees, as far from the trees as possible. Where seepage-water occurs throughout the season, fairly deep tiling is best for trees, and also prevents the tree roots from reaching the drains.

Septic Tanks and Sewage Disposal. — In Oregon, it is unlawful to discharge raw sewage into running streams. It is, therefore, necessary that sewage from rural dwellings and other buildings be rendered sanitary before it is discharged into running water. This can be accomplished most economically by means of the septic tank and the absorption system. The septic tank is merely an underground tank into which the sewage is discharged and allowed to undergo natural chemical and bacteriological changes for a period of eighteen to thirty-six hours, after which it can be discharged into the absorption system. The absorption system consists of an underground drainage system made of ordinary farm tiling, in which the direction of flow is reversed. The absorption system is usually constructed of 4-inch red clay tiles, laid with $\frac{1}{4}$-inch joints, at a depth of 12 to 15 inches below the ground surface. The fall is about 2 inches for each hundred feet. The total capacity of the tiles should be about 75 per cent of that of the discharge tank from which the sewage comes. The tiles may be laid in parallel branches, 5 to 15 feet apart, leading from the main outlet pipe. Sewage is discharged from the septic tank sud-

denly and in large quantities, so that the whole tile system will be filled at once. The sewage is then absorbed by the surrounding ground, and the soil bacteria destroy the harmful elements in the sewage. In case the soil is impervious or poorly drained, tile underdrains should be laid between 1 and

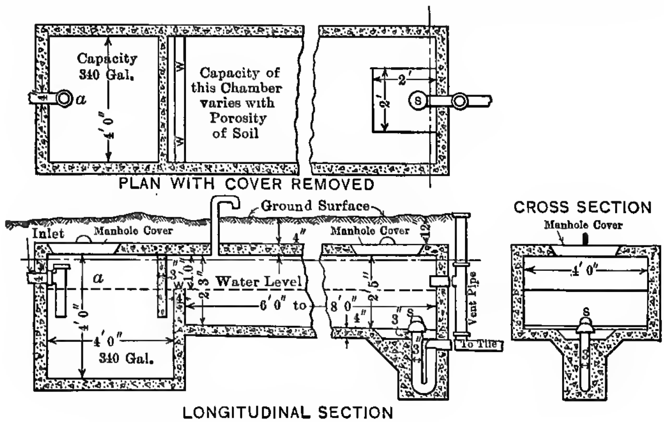

FIG. 88. Plan and sectional drawing of a septic tank.

2 feet below the absorption tiling, so as to prevent water-logging of the soil. The trenches in which the absorption tiling and drain-tiling are laid may be filled with graded gravel, or the whole area may be underdrained and prepared as a sand-filter. The capacity of the absorption system can be increased by the cultivation of grasses or lawn on the absorption field. The discharge from this underdrainage system is usually clear water, and can be turned, with safety, into any running stream.

Sewage-Irrigation. — In arid and semi-arid regions, economy is often effected by using sewage in the irrigation of truck gardens, and other agricultural land. In such cases the sewage is collected in artificial concrete storage basins or tanks, and by means of gate-valves distributed alternately on dry areas which are under cultivation. There is a close relation between irrigation and drainage; and some soils require both for their highest development. Droughty soils are best adapted to sewage-irrigation.

Road Drainage. — There is no factor entering into the construction of good roads that is more important than drainage. It is the very foundation of good roads. With proper drainage almost any road will be a good road; without it, no road, no matter what the cost, can remain a good road very long. Road drainage divides itself into two classes, surface-drainage and subsurface-drainage. Surface-drainage is the process of taking off the water that falls on the road from above or runs on to it from adjacent surfaces. Subsurface-drainage is designed to carry away the water moving up into the roadway from below. After water has reached the tiling through the surface of the road, it has done all the damage of which it is capable; the water should therefore be intercepted, both by sub-drainage from below and by surface-drainage from above, before it reaches the road and saturates it, or from the gravel shoulder of pavement to the ditch.

FIG. 89. A road badly in need of drainage.

To prevent water from standing in puddles on the surface and to prevent its penetrating the road, it is necessary to crown the road and keep the surface smooth and free from rocks and holes. The split-log drag is useful in maintaining a smooth, impervious surface on earth roads. For any surface like gravel or macadam, $\frac{1}{2}$ to $\frac{3}{4}$ of an inch for each foot of the half width of the road is sufficient crown; and for an earth road 1 inch is sufficient. On hill roads, "water-breaks" or mounds will help direct water from wheel-trails. Properly constructed side-ditches are necessary to carry away promptly and completely water that has run off the road or collected from adjacent territory. Such side-ditches need not be deep, but they should

be of such design or shape that they can be readily constructed and maintained with ordinary road machinery. No obstructions should exist between the center of the road and the side-ditch to prevent water from running directly from the road to the ditch.

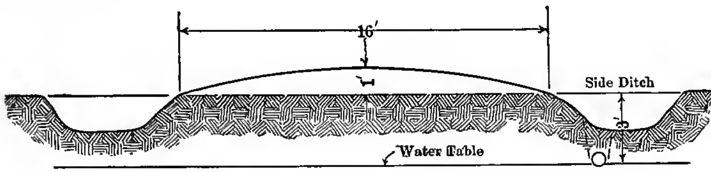

FIG. 90. Cross-section of road showing location of tile drain.

The tiling should be laid not less than 3 or 4 feet below the crown of the road, and in a uniformed grade-line. In case the road extends parallel with the direction of the flow of the ground-water, two lines of tiling, one on either side of the road, may be required. The waterway areas of all bridges and culverts should be ample, and the culverts should be constructed of durable material. Four-inch tiles with a fall of 0.3 foot to each 100 feet will usually be ample for underdrainage. The tiling should be placed on the higher side of the road and just inside the gutter. Water should be taken out of the ditches frequently, at least every 1000 feet in rolling countries. In very flat locations it is necessary to carry it a much greater distance. To prevent undermining there should be an outlet structure at the outlets of all culverts and drains.

Terracing and Drainage to Prevent Erosion

Direction and control of erosion and gullying are highly important, because the most valuable surface-soil is removed by these processes, or the surface disfigured and rendered difficult or impossible of cultivation. The eroding power of water varies as the sixth power of the velocity; and, to prevent destructive influence or runoff, the water should be kept spread out, so that it may be absorbed by the soil. Soils liable to erosion are those which are low in organic matter. Vegeta-

tion, which increases humus in the soil, terracing, underdrainage, and deep cultivation are means of preventing erosion.

Deep cultivation helps to conduct the water into the soil, by rendering the latter more spongy and increasing the amount of pore space; this is especially true when organic matter is turned under and incorporated with the soil.

Drainage will aid absorption and equalize the runoff, permitting greater amounts of the rainfall to be absorbed, and thus keeping the soil in good structure. Under these conditions, the soil is less likely to become puddled, and water is free to enter the deeper strata. Intercepting drains and collecting wells are often useful for the control of seepage in hill-lands. Catch-basins and properly constructed hillside ditches, in connection with some underdrains, will be of great value in controlling erosion.

FIG. 91. Tile washed out sweet clover in use to retain banks.

Vegetation and humus in the soil interrupt the progress of the water, so that some is absorbed and held by the vegetation on and over the surface. Humus is very spongy, and therefore improves the soil-structure, while its fibrous character helps to hold the soil particles in place. The use of meadows, pastures on the steeper slopes, and cover-crops in connection with cultivated crops on lands of moderate grades, will be of great value in the preservation of the soil.

Terraces may be made level or with a slight slope. Wherever practicable it is desirable to have the terraces from a broad mound which can be crossed at the time of planting and cultivation. Such a terrace does not harbor weeds or interfere with field operations. The North Carolina Experiment Station reports extended use of the sloping or Mangum terrace in

that state. The terraces are made by plowing and grading of the large back furrow which was laid around the hill, nearly on the contour and in reverse direction to that of the slope. The vertical interval between terraces is usually 4 or 5 feet, and the fall to the rod about 1 inch, or 6 inches to each 100 feet, in the direction of the contour. In laying out a terrace, the level is set up near the top of the hill at the central part of the field or ridge. Stakes are then set directly down the slope at vertical intervals of 5 feet. From these stakes, lines are laid out with a level, so as to locate the terrace across the slope with a fall of about an inch to the rod. Survey stakes are set each 50 feet, and a back furrow is plowed along the line of stakes, the grade usually being backed up the hill to one side and down the hill to the other side or outlet, on a grade of an inch to the rod. Terraces should be protected, where they discharge into the ditch, by having the water pass out through the banks in pipes. The plowing and grading is repeated until the terrace is about a rod wide and from 1 to 2 feet high at the crown. The solid seeded crops, such as peas, clover, oats, or rye, are used during the first years, until the terrace is settled. A V-shaped crowder, or terrace-drag, is useful in making the terraces. An A-level or carpenter's level may be used in place of a surveyor's instrument.

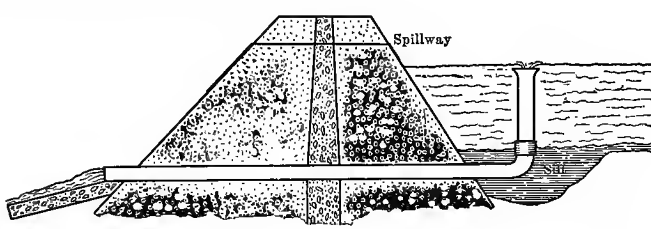

FIG. 92. Dam and relief drain to prevent gulling and to catch silt.

Gullying may frequently be controlled by placing a dam across the gulch, and carrying a drain of good capacity through this dam, near the bottom of the gulch. The up-stream side should be provided with a T, and jointed up-turned or vertical pipe, so that the clear water can be drawn off and the sediment

allowed to fill in above the dam. The outlet drain should be of good capacity; and it would be advisable to allow an ample-sized waste for protection in case of unusually heavy storms. Where fields are inclined to gully, the swales should be kept in redtop or blue-grass, instead of being broken when the field is plowed. Willows are sometimes planted along gulches to overcome the erosion.

QUESTIONS

1. Describe the proper method of drainage for barnyards.
2. Where should tiles be placed to drain a foundation?
3. What points should be observed in designing tiling for orchards?
4. How is sewage rendered sanitary by a septic tank?
5. Describe the general construction of a septic tank.
6. How may liquid drainage be disposed of, after it leaves a septic tank?
7. What useful disposition may be made of drainage from a septic tank and under what conditions?
8. What methods can best be used to dispose of surface-drainage on farm roads?
9. Where should tiling be placed in road drainage?
10. How are terraces located?
11. How are falling terraces constructed and maintained?
12. Describe methods for overcoming gullying.

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PART IV.— DRAINAGE SURVEYING

CHAPTER XXI

DRAINAGE SURVEYING AND PRACTISE

THE planning of drainage systems requires precision. A careful survey should always precede the construction work, in order that the completed system may be effective. The drains must be properly arranged, and the number of branch drains worked out with care and mathematical exactness.

FIG. 93. Class making a survey for tile drainage.

If the drainage system is simple, the plan may be easily made, and in some instances measuring instruments will be unnecessary. Usually, however, the system will be so large or so expensive, or the grade will be so flat, that a careful survey and the assistance of a competent drainage engineer will be needed. A good drainage specialist should possess a practical knowledge of the local rainfall, ability to estimate the amount of flood-water, knowledge of the subsoil and general

character of crops suited to the land, and experience in calculating the proper sizes of open ditches, as well as tile-drains. He should also be able to make the field survey with rapidity and accuracy, to record it properly and to interpret it. In addition he should have the tact, personality and control of temper which are necessary in dealing with men. He must be a man of integrity, resolute, yet discreet, of sound judgment, and proof against improper bias of any kind.

Instruments. — In laying out drainage systems, three surveying instruments, the chain, the tape and the level are necessary. The farmer should be more or less familiar with engineering technique, so that he may appreciate the work of the engineer, and be better qualified to understand when and where the services of the latter are really needed.

Fig. 94. Surveying instruments used in drainage work.

Chains. — There are two kinds of chains in common use, the surveyor's or Gunter's chain, and the engineer's chain. The Gunter's chain is 66 feet long, divided into 100 links of 7.92 inches each. One Gunter's chain equals 4 rods. One mile equals 80 chains, 1 acre equals 10 square chains. On account of its simple relation to the mile and the acre, the Gunter's chain is especially adapted to land surveys. The engineer's chain is either 50 or 100 feet long, and is divided into links of 1

foot each. Chains have been largely superseded by tapes. The chief advantage in the use of the chain is that it is not easily broken. The disadvantages are as follows: (1) a chain stretches or increases in length on wearing; (2) it is heavy and awkward for field use; (3) the links become distorted with rough usage, and this distortion changes the length of the chain; (4) the links may double back or kink, thus causing error; (5) it is not closely graduated to hundredths of a foot, as are some tapes.

There are three kinds of tapes in common use, the cloth, the metallic and the steel. Cloth tapes are of little service, for they stretch with usage.

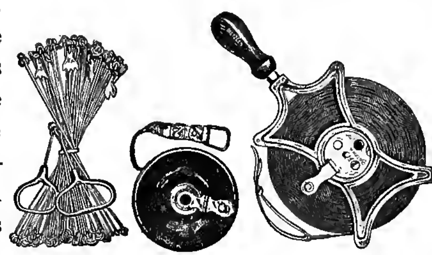

Fig. 95. Left, surveyor's chain; center, metalic tape; right, steel tape on reel.

Metallic Tape. — The so-called metallic tape is made of fabric, with fine wires woven lengthwise in the material, to prevent stretching. Such tapes are made in lengths of 25, 50 and 100 feet, and are graduated into feet, tenths, and half-tenths of a foot. They are convenient to use because they are of light weight and are easily read. The disadvantages in their use are two: they stretch to a certain extent when pulled, and they wear out very quickly.

Steel Ribbon Tapes. — Ribbon tapes may be obtained in various lengths up to 500 feet. The most common lengths are 50 and 100 feet. The shorter tapes are graduated into feet, tenths, and hundredths throughout their entire length; but the longer ones are graduated into feet only, the 5-foot marks being numbered, and each end foot being graduated into tenths for convenience. The advantages in the use of the steel ribbon tape are as follows: (1) a steel tape stretches very little with use; (2) it is light and easily handled in the field; (3) it does not become distorted without breakage; (4) it gives smaller subdivisions and thus may be more accurately read.

The disadvantages of a steel tape are that it breaks when it kinks, and that the marks may be hard to see.

Errors in Using the Tape or Chain. — Errors in the use of the steel tape are of two kinds, cumulative or compensating. A cumulative error is one that grows or increases with each application of the tape. A cumulative error may be due to imperfect vertical or horizontal alignment of the tape, or to incorrect length of tape.

A compensating error is one which grows alternately larger or smaller with successive applications of the tape, and may be due to the degree of tautness, the setting of the pin, or the swinging of the plumb-bob when chaining on steep slopes.

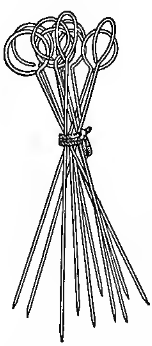

Fig. 96. Arrows or pins.

Method of Chaining. — A horizontal line is measured by two chainmen, using a chain or tape and a set of eleven steel marking pins. One man, called the head chainman, carries ten of the marking pins and the front end of the chain, while the rear chainman takes the eleventh pin and the rear end of the chain. The head chainman goes forward, keeping as nearly on line as possible. The rear chainman, starting over his point, places the head chainman in line with some object, such as a sighting rod which marks the other end of the line. The rear chainman holds his end of the tape at one side of the initial point or pin, so that it will not be disturbed before the forward pin has been set. When the head chainman is nearly in line, he holds a pin upright on the ground a foot or so from the end of the chain, and the rear chainman motions him to the right or left until his pin is on line. When the head chainman has the pin in line, he takes the precaution to see that there are no kinks and then stretches the chain tight and makes sure that there are no obstructions to cause bends in the chain. At the same time, the rear chainman holds his end of the chain on the pin and calls out, "Stick." The head chainman then places his pin at the end of the chain and calls back to the rear chain-

man, "Stuck." The rear chainman then pulls the pin at his end of the tape and keeps it as a record of the number of chain lengths measured. The chainmen then proceed one chain-length to the next pin. Just before reaching the next pin, the rear chainman calls out, "Chain," to give the head chainman warning that he has nearly reached the chain-length. The process of measuring chain-lengths is then repeated. When ten chains have been measured, the head chainman will be out of pins. He then calls to the rear chainman who brings forward the ten pins, the eleventh still remaining in the ground to mark the new starting point. The pins should then be counted by both chainmen. Every time ten chains are measured, a record is made in notebooks, which should be kept by both men, and the process repeated until the entire line is measured. Where the ground is so steep that a full chain-length cannot be used, care must be exercised that no errors are made. In such cases, fractional chain-lengths are used, and the operation is called "breaking chain."

The Level and Level Rod. — The instruments most useful to the farmer, as well as to the engineer, in laying out drains, are the level and rod. The use of these instruments is very simple and the theory can be mastered by any intelligent man in a short time. Skill in using them will come with practise. Leveling is a process by which heights or elevations of definite points on a line or area, above an arbitrarily adopted plane, are determined. This arbitrary plane is called a "datum plane," and is chosen so that it always lies below the lowest point which is to be determined. Thus, a point of 100-foot elevation is actually 100 feet above this imaginary datum plane. If the elevation of all points above the datum plane is determined, the datum plane itself being constant, the elevation of one point with reference to another is easily determined by the subtraction of their respective elevations.

The engineer's level consists of a telescope forming the line of sight, attached to a bubble-vial and a vertical axis or spindle. There are two types of engineer's levels, the dumpy level and

the wye-level. In the former the telescope is fixed to the support, while in the latter the telescope rests in a Y-shaped support, from which it can be easily and quickly removed. In the wye-level, the bubble-tube is attached to the telescope barrel on the under side. The telescope is attached to standards on Y's, which in turn are attached to the level on a vertical spindle, or axle, about which the whole instrument may be revolved. The whole is attached to a tripod head to which are also attached three wooden legs, similar to, but heavier than, those on a photographer's tripod. The important parts of the level are the eyepiece, the object-glass, the focusing screw, the bubble-vial, the adjusting screws, and the vertical action or spindle.

Use of the Level. — As the levelman looks through the telescope, there appear at a distance two black lines, one horizontal and the other vertical, crossing each other at the center of the telescope. These are called cross hairs. When the telescope is level, that is, when the level-bubble is in the center of the level-tube, the following facts are to be noted: (1) The line from the levelman's eye at the eyepiece of the telescope, and to the intersection of the cross hairs, is a level line and is parallel to the datum plane. (2) The height of this line above the datum plane is called the "height of instrument." (3) Every point of this line, produced forward or backward, is at the same height or elevation as is the instrument.

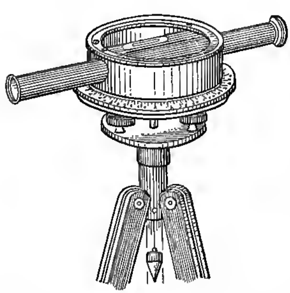

FIG. 97. An inexpensive farm level with horizontal circle for turning angles.

Cheaper Levels. — There are a number of cheaper levels that will serve, where there is a fair amount of fall to the drainage area. These are variously designated as drainage levels, grade-levels, explorers' levels, and architects' levels. They operate on exactly the same principle as the instruments already de-

scribed, differing from them principally in the grade of workmanship and material used in manufacture.

Where tiles of good size are to be laid with a fair fall, rather crude devices, costing only a few dollars, are sometimes used for leveling with satisfactory results. Some of these simple devices will be briefly described.

The carpenter's square and plumb-line level-device is made by fastening the ordinary carpenter's square on top of the stake with a plumb-line attached at the angle of the square. When the vertical leg is parallel to the plumb-line, the horizontal leg of the square is a level line and may be used as a line of sight in producing this level line for purposes of establishing grades.

The carpenter's level is a device that needs no description. It may be used by making T-shaped stands. The stem of the T is driven into the ground and the level set up on the arms of the T. It is leveled up by long, thin wedges under the ends, or by a hinge-joint at the junction of the arms of a T.

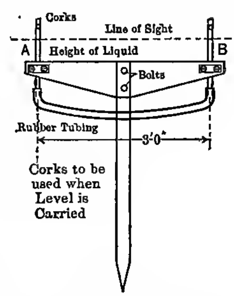

FIG. 98. Water or hose level (after Davidson).

The water-level consists of two vertical glass tubes attached at both ends of a T-shaped stand and connected by a few inches of rubber tubing. The stem of the T should be as nearly level as possible. Colored water in the tubes will rise to the same level in each tube, and a line connecting the surfaces of the colored water in the tubes will be a level line.

There are numerous other types of home-made levels, such as the plumb-bob and "A," carpenter's level, straightedge, etc.; but their accuracy is no greater than that of the devices already described, and they are not so convenient to operate.

The Hose Level. — Mr. J. O. Jeffrey in his text on land drainage describes a form of home-made device for running levels, which, if handled carefully, is an excellent and accurate leveling instrument. It consists of a long hose with glass

tubes connected on both ends, and depends on the simple principle that water seeks its own level. The hose is usually $\frac{1}{2}$ inch garden hose 60 feet long, and the glass tube may be made from ordinary steam-boiler water-glasses. The hose is filled with water, care being taken that no air-bubbles are entrapped; the water is then held within the hose by the levelmen, who keep their thumbs over the glass tubes while proceeding from one station to the next. The rods are made by nailing yardsticks to a narrow piece of board about 7 feet long.

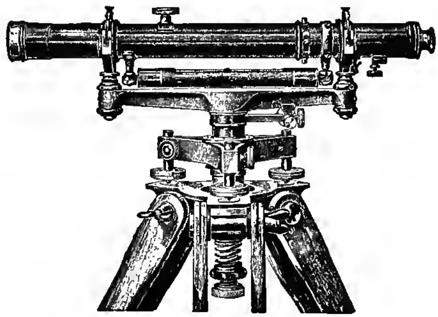

FIG. 99. An engineer's wye-level.

Level Rods. — Level rods are classified according to their construction as either self-reading or target rods, or they may be combinations of the two. Self-reading rods are those which can be read directly from the instrument by the levelman, while the target rods can be read only by the rodman. For drainage work, self-reading rods are preferable. The rod most used by engineers is the Philadelphia rod, which can be used either as a target rod or as a self-reading rod. It is graduated to feet, tenths and hundredths of a foot, graduations being plainly painted on the face of the rod. A target is provided, but it is not necessary to use it. The rod is made of two strips of wood, ordinarily $6\frac{1}{2}$ feet long, one of which slides in the groove of the

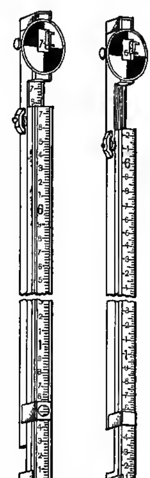

FIG. 100. Leveling rods; the one to the right is a non-speaking rod known as the New York; and the one to the left is a speaking rod known as the Philadelphia.

other. The target is free to move along the lower $6\frac{1}{2}$ feet of the rod, or it may be clamped in any position. A clamp is also provided for holding the two parts of the rod in any position desired. When the rod is fully extended, the graduations on the front faces of the two parts are continuous and the readings can be made directly by the levelman himself. When used as a target rod for reading above $6\frac{1}{2}$ feet, the target is clamped at the $6\frac{1}{2}$ foot graduation, and the readings are made from the scale on the back of the rod.

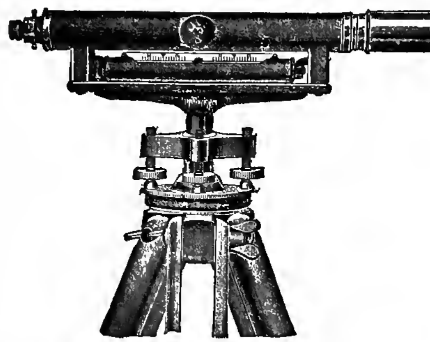

FIG. 101. A dumpy level.

The Flexible Rod. — This type of rod is a long strip of fabric, having the graduations painted in feet, tenths and hundredths of a foot as with the Philadelphia rod. It may be rolled up and carried in the pocket. When in use it is fastened with thumb tacks to a piece of pine board $\frac{3}{4}$ inch by 4 inches by 14 feet. When the leveling is finished the board may be discarded.

Preliminaries. — Before the use of the level is explained, some descriptions and definitions will be given.

Differential leveling consists in finding the difference of elevation between two or more points.

Profile leveling consists in finding the relative elevations of a series of representative points along a surveyed line, for the purpose of constructing a profile or vertical section. A fine thread and pins are useful in adjusting the grade lines.

A Contour line is a line all points of which are at the same elevation. *Contour leveling* is an application of the methods of profile leveling to the location of contour lines. Contour lines may be found either by locating points of equal elevation, or

by taking elevations at regular intervals and interpolating the contours from plotted data.

Cross-sectioning consists of staking out the limits of a transverse section of a ditch or levee, and usually includes an estimate of yardage.

Definitions. — A *datum plane* is a plane to which the elevation of each of the observed points is referred. It may be sea-level or an imaginary or assumed plane. *Bench Marks* (B. M.) are permanent objects, the elevations of which are determined or assumed, and recorded for future reference. Bench marks are taken at the terminals of the line and intermediate benches may also be used. *Turning Points* (T. P.) are intervening points upon which the level rod is held, for the purpose of determining the height of instrument (H. I.). *Stations* (Sta.) are points upon which the level rod is held. They are usually 100 feet apart. *Backsights* (B. S.) are readings on points of known elevation. *Foresights* (F. S.) are readings taken on points for the purpose of obtaining their elevations.

Backsights are taken for the purpose of obtaining a new height of instrument; they are plus quantities and are added to the elevation of the point sighted at. Foresights are minus quantities and are subtracted from the height of instrument to get the elevations of points.

Height of Instrument, (H. I.) refers to the sight-line or plane in which the telescope revolves, and from which the levelman makes his readings. *Elevation* (Elev.) is the vertical height of a point as compared with some reference point or datum plane.

Grade. — A grade-line is a line along which the water in the drain is to flow. In any particular drain, there may be a uniform grade throughout or different grades. The tile-base is fixed at an arbitrary depth at the outlet or head, and at other control points along the lines; and the fall between control points is prorated among the intervening stations.

Cut. — The cut, or depth of the excavation, is the difference between the ground elevation and the grade-line at each station. It is determined by subtracting the grade elevation of the point from the surface elevation of the same point.

Setting Up the Level. — Secure a firm set-up, and if the ground is sloping place two legs of the tripod downhill. After bringing the head of the tripod as nearly level as possible by changing the tripod legs, place the bubble parallel to an opposite pair of leveling screws and bring the bubble to the center, remembering that both thumbs turn out or both in, and that the bubble will go in the direction in which the left thumb moves. When the bubble is in the center, turn through 90 degrees and level over the other set in a similar manner. Care should be taken that the leveling screws do not bind, but they should be brought snug against the plate.

Ordinarily before taking any sights, the cross hairs are brought into the most distinct position possible by moving the eyepiece barrel. The telescope is then focused on a point; the eye is moved slowly behind the eyepiece, and if there is an apparent quivering of the cross hairs on the object, it signifies either that they are not in the most distinct position possible or that the object-glass is not clearly focused, or both.

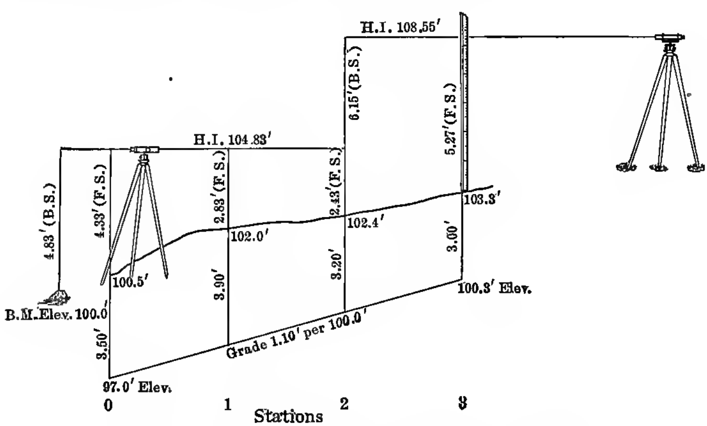

Fig. 102. Diagram showing method of using level.

The *adjustment* of the level consists in bringing the various parts of the instrument into proper relation to each other. Certain tests may be made, and the level may be adjusted if

necessary. An outline of the different adjustments will be given later.

The sketch will explain the work of differential leveling. In profile leveling, several foresights, called intermediate sights, may be taken at each set-up of the level.

Form for Field Notes.—A field book may be divided into six columns on the left-handp age and three or more on the right.

Proof. — The sum of the backsights minus the sum of the foresights on turning points should equal the difference in elevation of the first and last stations in the series. It is recommended that a return be made to the first bench mark.

How to Check Readings. — The extra man in the squad, if there be one, should go with the rodman, so as to get an extra check on the target readings. He may act as note-keeper.

Care of Field Equipment

In going through a narrow passageway, always carry the instrument in front of you. In going over a fence, place the level on the other side, setting the legs of the tripod well apart so that it will stand. In windy weather, set the instrument firmly on its legs so that it will not blow over. When shouldering the instrument, always slightly clamp the clamp-screws on the spindle. With the level, clamp the telescope so that it hangs down. Great care should be used in passing through timber with low branches.

Setting Up Indoors. — In setting up an instrument indoors, press the shoes firmly into the floor, putting each point into a crack, to insure spreading of the tripod legs. It is convenient to have a triangular frame of narrow strips of wood into which the tripod legs may be set. If the level is to remain for any length of time outside the rack, it will be best to unscrew the upper part from the tripod and place it in a safe position.

The Sun-Shade. — The sun-shade is a part of the telescope-tube, and should always be attached thereto, regardless of the weather, as the adjustments of a delicate instrument may be affected by a change of weight in its axis. In attaching or removing the sun-shade or the dust-cap, always hold the tel-

SURVEY FOR DRAINS FOR DAIRY BARN *May* 2, 1919

(Left-hand Page)						(Right-hand Page)		
Sta.	B. S.	H. I.	F. S.	I. S.	Elev.	Grade Elev.	Cut	Remarks
B. M.	4.83	104.83			100.00			Top of Fire Hydrant by Barn
0				4.33	100.50	97.00	3.50	
1				2.83	102.00	98.10	3.90	Fall 1.1′ per 100′
2				2.43	102.40	99.20	3.20	
T. P.	1.34	102.78	3.39		101.44			
B. M.			5.27		97.51			Nail in root of tree near 2 + 30
	6.17		8.66		100.00			
			6.17		97.51			
			2.49	←check→	2.49			

scope firmly with one hand and twist the shade or cap to the right with the other to avoid unscrewing the object-glass.

Setting Up in the Field. — When the instrument is set up in the field, the legs of the tripod should be brought to a firm bearing, with the tripod head approximately level. Give the tripod legs additional spread in windy weather and in places where the instrument may be subjected to vibration or other disturbance. On side-hill work, always place two legs down hill. It is much easier to keep the instrument level if two tripod legs, as well as an opposite pair of leveling screws, are placed in the general direction of the line of levels.

Exposure of the Instrument. — Never attempt to use a level in a rain storm. In threatening weather it is a good plan to carry a waterproof bag, and cover the instrument with it in case of rain. Excessive dampness fogs the lenses so that it is impossible to work. Never put a wet instrument into the case, but wipe it thoroughly dry before returning it; otherwise the lenses may become fogged so that it will be impossible to use them when the instrument is taken out of the case. The instrument should be protected from dust and dirt and should not be subjected to sudden changes of temperature. When an instrument is brought from a cold to a warm temperature, it should be covered with a bag or cloth to protect it from condensing moisture. Never leave an instrument unguarded or exposed, in such places as pastures, or drive-ways, or where blasting is in progress. Never leave an instrument standing in a room on a tripod over night.

Manipulation of Instrument. — Engineering instruments are delicate, and the operator should cultivate the habit of delicate manipulation, from the beginning. The parts of these instruments, when once injured, can never be restored to their original perfect condition. Carelessness in the use of field instruments is indicative of lack of skill and experience. When any screw or part of the instrument works with difficulty immediate attention should be given to it, and repairs made if necessary. Delay in making repairs often permanently injures the instrument.

Foot Screws. — If the screws used in leveling the instrument are too loose, it will rock on the tripod, and accurate work cannot be done. If the screws are too tight the instrument will be strained and damaged and the observations will be less exact. In leveling an instrument, therefore, the foot screws should be dropped just to a snug bearing; but needless turning and wear of the foot screws may be avoided if the plates are brought about level when the instrument is set up. This may be accomplished by shifting the legs upon the ground. In leveling, an opposite pair of foot screws should be shifted in the general direction of the line of foresight before leveling up.

Clamps. — The ears of all clamp-screws on engineering instruments are purposely made small to prevent abuse. Do not overstrain the clamps. Find out, by experiment, just how tight to clamp the instrument in order to prevent this, and then act accordingly. Never touch the capstan-headed adjusting screws on an instrument, unless you are positive that it is necessary and that you have the authority.

Lenses. — The lenses of a telescope should never be removed or rubbed, as this will mar the finish which is given to their surface, in the final stage of manufacture, by the bare human hand. Should it be absolutely necessary to clean the lens, do so cautiously, using a very soft rag, and taking care to avoid scratching or marring the polished surface. A little alcohol on a rag will be helpful in removing grease. Protect the lenses from flying sand and dust, which will in time obscure the image in the lens.

Tripod Cleaning. — Clean the tripod shoes before bringing the instrument indoors. Leave the tripod standing on its three legs.

Leveling Rods and Flagpoles. — Leveling rods, stadia rods and flagpoles should never be left leaning, or placed where they may fall. Avoid injury to the clamps, targets and graduations, and do not mark the graduations with a pencil. Needless exposure of rods to moisture or sun will injure them materially. In carrying a rod, let the ungraduated edge rest on the shoulder.

Chains and Tapes. — Chains and tapes are liable to break, especially in cold weather. They should be handled carefully and not jerked. On driveways, streets, etc., especial care should be taken to protect the tape. Ribbon tapes should be done up in 5-foot lengths in figure-eight form, unless reels are provided. The figure-eight may then be thrown into a circle. Such tapes should be wiped clean and dry at the end of each day's work. Great care should be used in cleaning, when using a tape near salt water.

In folding up a surveyor's chain, begin at the center and fold the chain two links at a time.

The Planetable. — The planetable is an instrument by means of which points are located in the field directly on the map, by graphical methods. The map is placed on a drafting board which is fastened to a tripod. The board may be revolved about a vertical axis. Traverse lines and points to be mapped are plotted by means of a ruler or straightedge to which a line of sight is attached. This line of sight is usually a telescope with cross hairs, the whole, with straightedge, being called an alidade. From a mathematical standpoint the planetable is not an accurate instrument, but from a practical standpoint it is most useful and sufficiently accurate to compete with the ordinary office methods of plotting. All errors become inappreciable when reduced to the ordinary scale of maps.

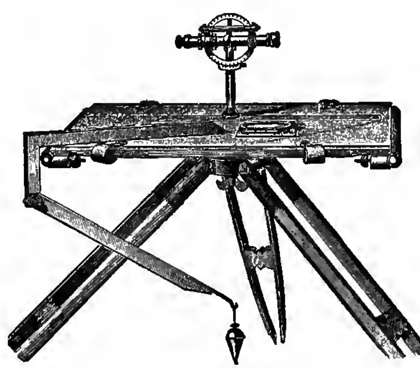

Fig. 103. A planetable.

Mapping directly by use of a planetable has the advantage of dispensing entirely with field notebooks and saving the trouble of plotting from field notes. Planetables are of several kinds and sizes; but the one most useful in drainage work is

the traverse planetable, which consists of a board about 15 inches square, mounted on a light tripod and having a small compass needle, or declinator, set in one edge of the board and flush with its top.

The directions of the lines on the map are determined by an instrument called an alidade, which consists of a ruler or straightedge, with two vertical sights, like those on a surveyor's compass, mounted on both ends of the ruler.

In tracing out a drainage line the instrument is set up at alternate stations only, the unoccupied stations consisting of natural objects occurring along the line of traverse, such as trees, stumps, roads, fence-posts, etc.

In sketching contours, an alidade equipped with telescope and stadia hairs is desirable. A skilled operator can get approximate elevations and contours with a traverse-table and ruler.

In very accurate planetable work, the planetable is set up at every station, and the map is oriented by putting the fiducial edge of the alidade on the last foresight and turning the table until the line of sight points to the last station occupied. In traversing, where every alternate station only is occupied, the orientation is checked by means of the declinator or magnetic needle.

Adjustment of the Wye-Level

Adjustment I

To Make the Line of Sight Coincide with the Axis of the Telescope-Tube.

Set the level up firmly, with one pair of diagonally opposite leveling screws in line with a distant object to be sighted at. Focus the telescope upon the object, clamp the horizontal motion, and, by means of the leveling screws, make the horizontal cross hair hit a definite point, such as a pin or nailhead. Rotate the telescope-tube through 180 degrees in the wyes, and see if the cross hair still falls upon the distant point. If so, the adjustment is correct; if not, mark the second sight and bring the cross hair halfway back to the first point by means

of the capstan-headed screws at the side of the telescope. Bring it the rest of the way back by means of the leveling screws. Make a similar test for the vertical cross hair and, if in error, correct by the capstan-headed screws at top and bottom of the telescope.

Check: Again rotate the telescope 180 degrees in the wyes, and see if the intersection of the two cross hairs still falls upon a fixed point. If not, repeat the process until it does.

The line of sight is then coincident with the axis of the telescope-tube, and, assuming that the rings are of the same size, it is parallel to the axis of the wyes.

Adjustment II

To Make the Bubble-Tube Parallel to the Axis of the Wyes and Hence to the Line of Sight.

With the level firmly set up, center the bubble first over one pair of leveling screws, and then over the other. Center it more carefully over the first pair, and clamp the horizontal motion. Remove the telescope from the wyes, turn it end for end and replace it. If the bubble is still centered the adjustment is correct; if not, bring the bubble halfway back to center by means of the adjusting screws at one end of the bubble-tube. Then center the bubble by means of the leveling screws.

Check: Again change the telescope-tube end for end in the wyes, and see if the bubble remains centered.

Adjustment III

To Make the Bubble-Tube Perpendicular to Axis of Revolution.

After adjustment II has been completed, the telescope-tube is replaced in the wyes in its original position, and the bubble is carefully centered. The horizontal clamp is loosened, and the level is revolved 180 degrees about the axis of revolution. The bubble should still be in the center; if it is not, bring it halfway to the center by means of the large Y nuts at one of the wye posts. Bring the bubble the rest of the way back by means of the leveling screws.

Check: Again revolve 180 degrees about the axis of revolution and see if the bubble remains centered.

Adjustments of the Dumpy Level

The Horizontal Cross hair. — Level the instrument and sight the horizontal cross hair at some well-defined point. Revolve the telescope slightly about the vertical axis by means of the leveling screws. If the point appears to move off the hair, rotate the cross hair ring until the point appears to remain on the line.

The Bubble Adjustment. — To make the bubble-tube perpendicular to the vertical axis of the instrument. The construction of the dumpy level makes it necessary to complete this adjustment before making the line of sight parallel to the bubble-tube. Center the bubble over one pair of foot screws, turn the instrument 180 degrees about the vertical axis. Move the bubble *halfway* back to the center by means of the capstan-headed adjusting screws at one end of the bubble-tube. Repeat for a check.

The "Peg" Adjustment. — To make the line of sight parallel to the bubble axis: Drive two pegs on slightly sloping ground 200 feet or more apart; mark them A and B. Set the level midway between the two stakes, in which case the error of the instrument will be equal at each station and the true difference in elevation will be determined. Find the difference in elevation by taking the difference of rod readings on the two pegs. Next set up near peg A, and take a rod reading on this point; with the difference of elevation already found by having set up between the two stakes, find the proper rod reading on the point B. Take a rod reading on B, and if this reading is in error, bring the horizontal cross hair to the calculated reading by means of the capstan screws on cross hair rings. Check by repeating the readings on both points, having the bubble in the center for both sights.

The "peg" adjustment may be used for checking the combined first and second adjustments of the wye-level, which it may replace.

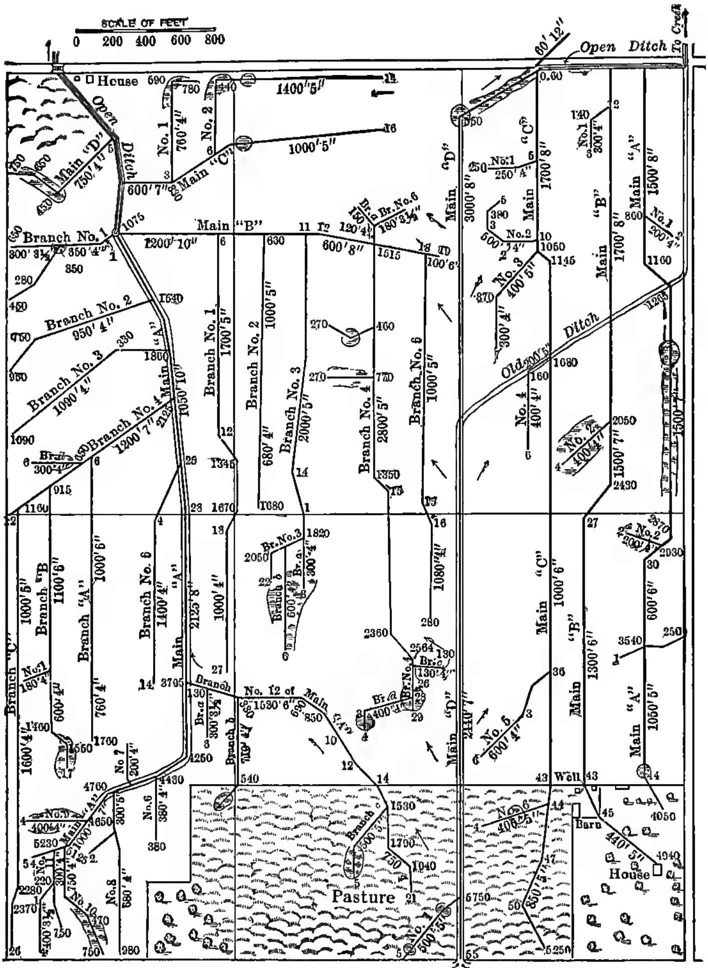

FIG. 104. A drainage map for 480 acres. From Farmers Bulletin 187 Drainage of Farm Lands. U. S. Department of Agriculture.

Maps and Records of Drainage. — It is important to keep records of the location and depth of tile-lines. When drained land is sold, a map showing the location of any tile-lines should

accompany the deed. This enables the owner to make any needed extensions or repairs.

In mapping, drawings should be centered in rectangular areas. Proper scale, titles, and legends should be used, and all notations neatly made. A map may be laid out with rectangular areas by drawing horizontal lines with T-square, and perpendicular lines with triangle resting on the T-square. Regular symbols have been developed for representing streams, drains, roads, and other objects; and the student should learn to read and to make maps with neatness and facility. Contour lines are lines passing through points of equal elevation such as shore lines at different stages of water.

The contour interval is the vertical distance between contour lines on a contour map, which is a map showing the topography or lay of the land. Such a map is useful in the design of drains, to secure proper grades.

A profile map represents a section in relief. In case of a tile-drain, it represents the surface and grade-line, as though cut and exposed to view from the side. The depth to dig and height of grade-line at each station can be represented thereon. Studies of water-table and subsoil conditions can be similarly plotted on the profile. Different scales may be used to represent horizontal and vertical distances if desired.

Blue-Printing. — Maps made with india ink on tracing cloth or thin coördinate paper may be reproduced by blue-printing. The drawing is placed in the print-frame with the ink next to the glass. The blue-printing paper is placed back of this, the sensitized or colored side being toward the glass. Expose to the light for such a length of time as tests show to be necessary. Then rinse promptly in a bath before hanging up to dry.

QUESTIONS

1. Define: surveying, compensating error, cumulative error.
2. Describe: engineer's chain, Gunter's chain, metallic tape.
3. State the advantages and disadvantages of chains, metallic tapes and steel ribbons.
4. What is meant by "chaining"?

5. What is meant by "breaking chain"?
6. What is meant by "tallying"?
7. Describe two methods of measuring an angle with a tape.
8. Explain the principle of the vernier scale.
9. Define, "declination," "magnetic bearing," "true bearing."
10. Describe the present method of land subdivision.
11. Define: "legend," "scale," "profile."
12. Define "level lines."
13. What is a "speaking rod"?
14. Define: "height of instrument," "backsight," "foresight," "bench mark."
15. Upon what principle does direct leveling depend?
16. Name the leveling instruments.
17. Name the parts of the level.
18. Define "grade," "gradient," "proof."
19. Describe three adjustments of the wye-level.
20. Why is it hard to carry a line of levels over a hill?
21. State the ultimate object sought in adjusting a level.
22. Why is it best to set up a level midway between two points upon which readings are to be taken?
23. Define, "contour map," "contour line," "contour interval."
24. Describe two methods of tracing a contour line in the field.

REFERENCES

Pence and Ketchum. — Manual of Surveying.

Breed and Hosmer. — Principles and Practice of Surveying, John Wiley and Sons, Inc.

APPENDIX

FARM DRAINAGE LABORATORY EXERCISES

Numerous preliminary exercises should be undertaken and performed successfully before practical drainage construction is attempted. The following problems are given with intention of familiarizing the student with the use of the level and other field tools necessary for successful work.

I. Chaining Practice.

(1) Learn to handle the chain or tape and the pins. Estimate, pace, and then chain a line over a hill between two points not visible from each other. Repeat this, each man acting as "lead man" or as "captain," then check results.

(2) To set a stake in a line perpendicular to a given line at a given point, the stake being over 150 feet from the given line.

(3) To find where a perpendicular from a given point without a line will meet that line, the given point being over 300 feet from the given line.

(4) To establish a second point that shall make, with a given point, a line parallel to a given line. The parallel lines are to be over 140 feet apart.

(5) To measure the distance between two points inaccessible from each other.

II. Leveling Practice.

(1) Define: datum plane, bench mark, stations, backsight, height of instrument, foresight, elevation.

(2) To find the difference in elevation of two points and the bench mark, stations being at least 200 feet apart, (*a*) when the difference can be found by one setting of the instrument, (*b*) when the difference cannot be found by one setting of the instrument.

(3) To find the difference in elevation of six stations and the bench mark. Stations 100 feet apart, (*a*) when all the readings can be taken by one setting of the instrument, (*b*) when no more than two readings can be taken from one setting of the the instrument. Sketch a profile of (3) on profile or coördinate paper.

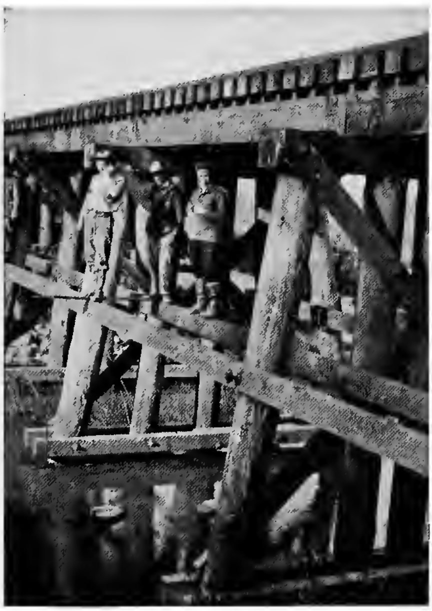

FIG. 105. Students measuring runoff with current meter.

(4) Find difference in elevation of two points not less than half a mile apart, and re-check.

III. Examination of a tile system in the field. Examine and make a sketch.

IV. A study of the effect of tile-lines on the water-table. Note soil strata, elevations and plot profile. (Plate I-a.)

V. Study soil, subsoil, and water-table on a low area needing drainage. Sixty to one hundred stations. Prepare soil and water-table profile map on two lines of boring. (Plate I-b.)

VI. Prepare a contour map of sixty to one-hundred stations, showing surface of soil and water-table. (Plate II.)

VII. Methods of staking out a drain system after having decided on a location. Name of lines run. Setting of stakes. Distance between stations, etc. Find the elevations of all stations.

VIII. Measurement of runoff by use of floats, and by use of the Cipoletti weir method.

IX. Find the grade-line of the tiling under the soil and figure the fall per hundred feet; find the cut at each station; and figure and make typewritten estimate on the cost of the system. Prepare profile map of main drain and the longest lateral, on coördinate tracing paper, showing "cut" and "gage height" at each station. (Plate III.)

X. Make record of drainage system on a contour map by means of planetable.

XI. Practice in setting grade-laths.

XII. Each student will be given practice in preparing trench and laying tile.

XIII. With a hammer and chisel, cut a hole in an 8-inch tile large enough to receive a 3-inch tile.

XIV. Determination of soil-moisture and soil-temperature in drained and undrained plots.

XV. Inspection of a proposed drainage district.

XVI. Trip to concrete and clay tile plants.

XVII. Make a blue-print from Plate III.

Fig. 106. One of the larger pumping plants in the west is in use by Reclamation District No. 108 near Woodland, California, to control water on Sacramento River bottom lands. This plant consists of five 48 inch Wood-screw pumps, driven by five 175 Horse power direct connected motors. The 48 inch pumps discharge approximately 100 second feet each. The electric motors are in a water tight basement. The cost of replacing the complete plant at the present time would be perhaps $500,000. These pumps are said to be very efficient when operating against a low head and are coming to be much used for drainage.

In Reclamation District No. 108 water is pumped from the river for the irrigation of over 100,000 acres the bulk of which is

rice land and large pumping plants are provided to pump out drainage and flood waters from the lower part of the project. It is necessary to keep the surface of the rice land covered for several weeks but provision must be made to draw off the

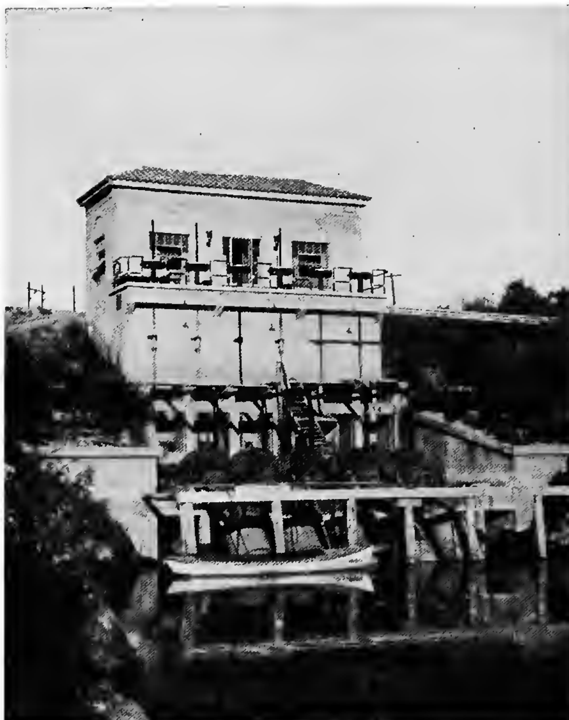

Fig. 106.

water before harvest as well as to protect against flood water. Water grass, cattails and tules become troublesome after two or three years of rice growing and a cultivated crop such as Egyptian corn is then used to clean up the land. The general plan of drainage is to provide open ditches every half to three fourths of a mile to draw off the water below the irrigation system. In some instances the irrigation water must be flumed

across these open drains. The soil is heavy clay and this together with the large volumes to be handled make underdrainage impracticable.

Pumping plants are located on firm ground and not over natural channels the water being led from the slough or ditch by a cut to the point where it is pumped out. Suction and discharge pipes are placed low with ends submerged to avoid use of unnecessary power. Large radius turns in the pipes are important for this reason also. Cement collars with good wing walls, trash racks, emergency gates and shelter are necessary for protection. The general subject of design of installation of drainage pumping plants is discussed in connection with the drainage of tide and overflowed lands. The length of period necessary to pump; kind of soïl and value of crops affect the feasibility of pumping for drainage. The total annual cost must be held down to a few dollars an acre to make pumping practicable for ordinary field crops.

TABLE VIIb*

Values of Coefficient c for Use in Kutter's Formula

	r ft.	N = Coefficient of Roughness					
		.017	.020	.025	.030	.035	.040
		c	c	c	c	c	c
S = 1 in 20,000 = .264 ft. per mile	1	77	64	49	40	34	29
	2	94	79	62	51	44	38
	3	104	88	71	59	50	44
	4	111	95	77	64	56	49
	6	122	105	85	72	63	56
	8	129	111	91	78	68	61
	10	134	116	96	82	72	64
	16	144	126	106	91	81	73
	20	149	131	110	96	85	77
S = 1 in 10,000 = .528 ft. per mile	1	81	67	52	42	35	31
	2	96	81	64	53	45	39
	3	104	89	71	59	51	45
	4	111	94	76	64	55	49
	6	119	102	84	71	61	54
	8	124	107	88	75	66	59
	10	128	111	92	78	69	62
	15	135	118	98	85	75	68
	20	139	122	102	89	79	71
S = 1 in 5000 = 1.056 ft. per mile	1	83	69	54	44	37	32
	2	97	82	64	54	45	40
	3	105	89	72	59	51	45
	4	111	94	76	63	55	48
	6	117	100	82	69	60	53
	8	122	105	87	73	64	57
	10	125	108	89	76	67	60
	15	131	113	95	82	72	65
	20	134	117	98	85	76	68
S = 1 in 2500 = 2.112 ft. per mile	1	85	70	55	45	37	32
	2	98	83	65	54	45	40
	3	105	89	71	59	51	45
	4	110	94	76	63	55	48
	6	116	99	81	69	60	53
	10	123	107	88	75	66	59
	20	131	115	96	83	73	66
S = 1 in 1000 = 5.28 ft. per mile	1	86	71	56	45	38	33
	2	98	83	66	54	46	40
	3	105	89	71	59	51	45
	4	110	93	75	63	54	48
	6	116	99	81	68	59	52
	10	122	105	87	74	65	58
	20	129	113	94	81	72	65

* From Trautwine's Engineers' Pocket Book.

TABLE VIIB (*Continued*)

VALUES OF COEFFICIENT c FOR USE IN KUTTER'S FORMULA

S = 1 in 100 = 52.8 ft. per mile	1	87	72	56	45	38	33
	2	99	83	66	55	46	40
	3	105	89	71	59	51	45
	4	109	93	76	63	55	48
	6	115	99	81	68	59	52
	10	121	105	86	74	65	58
	20	128	112	93	80	71	64

	r ft.	N = Coefficient of Roughness					
		.013	.015	.017	.020	.025	.030
		c	c	c	c	c	c
S = 1 in 2500 = 2.112 ft. per mile	1	115	98	85	70	55	45
	2	130	112	98	83	65	54
	3	138	119	105	89	71	59
	4	142	124	110	94	76	63
	6	149	130	116	99	81	69
	10	157	138	123	107	88	75
	20	164	146	131	115	96	83
S = 1 in 1000 = 5.28 ft. per mile	1	116	99	86	71	56	45
	2	130	112	98	83	66	54
	3	138	119	105	89	71	59
	4	142	124	110	93	75	63
	6	149	130	116	99	81	68
	10	155	136	122	105	87	74
	20	163	144	129	113	94	81
S = 1 in 100 = 52.8 ft. per mile	1	117	99	87	72	56	45
	2	130	112	99	83	66	55
	3	138	119	105	89	71	59
	4	142	123	109	93	76	63
	6	148	129	115	99	81	68
	10	154	136	121	105	86	74
	20	161	143	128	112	93	80

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